THE SERPENTINES OF HARFORD COUNTY, MARYLAND

A dissertation submitted to the Board of University Studies of the Johns Hopkins University in conformity with the requirements for the degree of Doctor of Philosophy

BY

ALBERT JOHANNSEN

1903

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THE SERPENTINES OF HARFORD COUNTY

INTRODUCTION

Location of Area

There is a narrow region extending through Maryland and through Pennsylvania, New Jersey, and Delaware on the north; and through Virginia, North Carolina, South Carolina, Georgia, and into Alabama on the south, throughout which are numerous disconnected areas of serpentine and talc rocks. The general distribution is shown on Plate I, but owing to the small scale of the map many minor areas had of necessity to be omitted. The geology of much of this region has never been thoroughly mapped and it has been impossible to obtain data for more than a general platting of these areas, especially to the south.

The Piedmont Plateau

All of these serpentine and talc bodies lie in the region known as the Piedmont Plateau. This is a region of folded, crumpled, highly metamorphosed, and crystalline rocks extending from New York to Alabama. A similar district occurs to the northward and extends through Rhode Island, Connecticut, eastern Massachusetts, southeastern New Hampshire, and along the coast of Maine. The southern area widens southward until it is 300 miles broad in North Carolina. South of this it is not so well defined and gradually disappears beneath the Coastal Plain of Alabama. To the east the boundary is well marked throughout the greater portion of its extent. Resting upon the upturned edges of the hard, compact, crystalline rocks of the Piedmont Plateau are the loosely consolidated, horizontal beds of clay, sand, and gravel of the Coastal Plain. These Mesozoic and Cenozoic deposits, with their comparatively low dip, have been much less eroded than the older rocks of the Piedmont, and the physical features, which have been formed to a great extent by the drainage, stand in great contrast with

the topography of the latter. Throughout its entire extent the eastern boundary corresponds closely to what is known as the "fall line." North of the Roanoke River in Virginia this line is near the head of the tidal estuaries. At Trenton, New Jersey, the falls are several miles above the southern boundary of the Philadelphia gneiss. Above Havre de Grace, on the Susquehanna, the falls are about the same distance above the head of the tidal estuary. The falls of the Potomac and the end of the Piedmont are several miles northwest of the city of Washington.

South of the Roanoke, the Coastal Plain sediments end above tidal level and the boundary of the Piedmont swings to the west and ends beneath the Mesozoic and Cenozoic rocks of Alabama. Throughout the region south of Virginia the boundary is, therefore, less clearly defined, and the sediments scantily cover an intermediate zone of varying width, making the establishment of a clearly defined line impossible. Though the fall line at the north is not often a sharply defined scarp and the deposits of the Potomac and Pleistocene sometimes overlap the boundary, yet the physiographic contrast and the petrographic difference in the rocks make the division a sharp one.

The western boundary of the region is not so well marked petrographically, but the broken, rounded hills stand out in strong contrast with the quartzite crest of the Blue Ridge. The rocks, highly metamorphosed in the eastern part of the Piedmont region, gradually become less so and pass into the less contorted and unaltered Paleozoic rocks of the Appalachian zone. South of Virginia the western or northwestern boundary is more clearly marked by what is known as the "Cartersville Fault".[1] This is an overthrust fault with an overlapping in some places of as much as 11 miles. West of this fault the rocks are unaltered Paleozoic sediments, and the overlying metamorphic rocks form a nearly continuous line of bluffs of from one hundred to three feet in height.

[1] Hayes, C. Willard. "The Overthrust Faults of the Southern Appalachians." Bull. Geol. Soc. Amer., 1890, v. II, p. 147.

THE ROCKS OF THE REGION

All of the rocks which occur in the Piedmont area are highly metamorphosed and crystalline, and extend with a general northeast-southwest strike across the plateau. The major portion of the rocks are mica-gneisses and phyllites into which have been intruded granites, gabbros, peridotites, and pyroxenites. The gneisses and phyllites are considered, for the most part, as sedimentary rocks in which the original character and bedding have been obliterated by subsequent metamorphism due to earth-movements, the intrusion of other rocks, and the action of underground waters. It is not at all improbable that with the original sedimentary rocks were associated igneous and eruptive rocks. It is, in fact, more than probable that this was so; but whatever the character of the original rocks, their former characters have been so changed that we can only say that some, at least, were sedimentary. Since the mineral constituents of the sedimentary rocks were derived originally from igneous rocks, one can easily see that when highly metamorphosed, it must be impossible to determine their origin.

The groups of rocks which are of greatest importance in this region are the gneisses, phyllites, granites, quartzites, gabbros, diorites, peridotites, pyroxenes, and limestones. Of these the gneisses and phyllites are the ones most widely distributed.

THE GNEISS

This rock varies greatly in character in different parts of the area and even in areas not far removed from one another. It ranges in color from a white to dark-gray or black, and in texture from very coarse and friable to very compact, homogeneous, almost pure quartz rock. At times it consists of feldspar and quartz with but little mica, and again it shows but little besides mica or hornblende. In many places the rock is so massive that even in quite large pieces it is impossible to see the parallel arrangement of the constituents; in others, there is an exceedingly fine parallel arrangement of the minerals. Very often this banding becomes exceedingly fine, and its crumplings, twistings, and foldings show that the rock has been subjected to repeated dynamic action.

THE PHYLLITE

These rocks are intermediate in character between the slates and the gneisses. They are essentially fine-grained mica-schists. The chief mineral is generally mica having its flakes parallel with the cleavage or schistosity of the rock. Associated with this is quartz, which, with the mica, forms the chief part of the rock. In many places garnets are very abundant in the rock, often forming as much as one-third of the bulk. Tourmalines are also very abundant in the quartz in many localities.

THE GRANITE

The granites in general are of medium fine-grained texture and are usually compact and homogeneous. In composition they vary somewhat, some carrying biotite, muscovite, hornblende, epidote, allanite, or zircon. The "granite" of Port Deposit, really a monzonite, is somewhat banded and consists of orthoclase, oligoclase, mica, and quartz. The Ellicott City granite is distinguished by the presence of large Carlsbad twins of orthoclase.

The granites are both older and younger than the other eruptive rocks with which they are associated. Their eruptive origin is clearly shown by their diverging apophyses, by the inclusions of the rocks through which they penetrated, and by the crumpling and contact-metamorphisms of the neighboring rocks.

THE QUARTZITES

A small portion only of this area consists of quartzites. It consists of quartz and muscovite in thin layers. In the micaceous layers are many fragments of stretched tourmaline, indicating a movement after the crystals had been formed.

THE GABBRO

This rock consists of hypersthene, diallage, bytownite, and magnetite, with some hornblende and apatite. It is generally of fine grain, massive, and very dark in color. The rock varies in texture as well as

mineralogical composition. When the ferro-magnesian constituent is principally an orthrombic pyroxene the rock becomes a norite. In many places the rock has been metamorphosed and passes into a schistose rock—the meta-gabbro. When the pyroxene is replaced by hornblende the rock becomes a gabbro-diorite.

THE DIORITE

The diorites closely resemble the granites in appearance, differing in the predominance of a plagioclase feldspar over the orthoclase. They always contain hornblende and generally also biotite. Quartz may or may not be present. Diorites are of much less importance in Maryland than either the gabbro or granite, and are much less widely distributed.

THE LIMESTONE

The limestones consist of marbles, limestone breccias, and impure limestones. The marbles vary in texture from a fine-grained dolomitic marble to a coarse-grained rock with but little magneisa. They are often accompanied by tremolite, muscovite, phlogopite, tourmaline, scapolite, quartz, pyrite, and rutile. All of these occur in layers, corresponding to the bedding. In Carroll and Frederick counties a mottled red and white marble known to the trade as "Potomac marble" or "Calico rock" is found. It consists of subangular fragments of limestone, quartz, slate, granite, and porphyry in a red ferruginous cement. It may have originated as talus slopes which were later cemented.

THE PERIDOTITES AND PYROXENITES

These are the youngest of the eruptive rocks in the region. They consist of the basic end of the gabbro magma. The peridotites consist of olivine and pyroxene, with more or less magnetite; the pyroxenite, of bronzite and diallage. Both of these rocks are generally much altered. The pyroxene, when it occurs alone, passes into secondary hornblende, and this in turn to talc; tremolite and chlorite being usually associated in the talc beds. The peridotites, consisting of olivene with pyroxene, usually alter to serpentine; the serpentine rocks generally containing secondary hornblende formed from the diallage. Neither

of these rocks cover large areas but usually occur in small lenses and stringers. North of the Carolinas the rocks are generally altered; farther south they are very much less so changed.

The sequence of the intruded rocks as given by Dr. F. Bascom for Cecil County[2] is as follows, the granites being considered by her as first intruded in the area which she describes: Granite, Meta-rhyolite, Gabbro, Pyroxenite, Peridotite.

THE SERPENTINE AREA

The region of the serpentine stands out prominently in this area of crystalline rocks. The landscape in general is characterized by great diversity of aspect; by rounded hills with U-shaped valleys between—a topography caused by long continued erosion upon the various kinds of rock forming the plateau. The hills are deeply covered with soil and along the roadside large trees make pleasant shade. In the serpentine areas, however, the trees are stunted and the fact that he is walking or driving over a serpentine area is brought forcibly to the notice of a traveller during the summer by the intense heat of the sun which beats down through a growth of stunted oaks, scrub pines, and mountain laurel upon the heated soil, through which everywhere project boulders of the country rock. These areas are known throughout the country as the serpentine "barrens." Wild, uncultivated, almost unsettled, they stand in great contrast to the surrounding rich and prosperous country. The sterility of the soil may be explained in several ways. Owing to the nature of the rock it decomposes very slowly and the products of decomposition may be washed away nearly as fast as they are formed. Consisting, as it does, of silica, magnesia and iron oxides it lacks the lime and potash necessary for the nutrition of plants. It may may be, as suggested by Dr. Loew[3] of the Department of Agriculture, that the preponderance of magnesia over lime may be detrimental to

[2] Bascom, F. "The Geology of the Crystalline Rocks of Cecil County." Md. Geol. Survey, Cecil County, 1902, p. 110.

[3] Loew, Oscar. "Physiological Rôle of Mineral Nutrients." Bull. No. 18, Div. of Vegetable Physiology and Pathology, U. S. Dept. Agri., 1899, p. 42.

plant life owing to the fact that the capacity for food assimilation by the plant may be altered by the substitution of magnesia for lime in the cells.

The color of the soil varies although it is generally of a deep-red when of some thickness. In the shallower portions it is of a lighter color, even yellow or yellowish-green, and from this ranging through all shades of red to an exceedingly dark-red color due to the iron oxides. The soil generally is not more than 6 or 8 inches in depth and even that is attained usually only in the interstices of the broken and fractured rocks. It is quite possible that the slight depth and the consequent inability to retain moisture, may account in large measure for the unproductiveness of the soil.

THE DISTRIBUTION OF THE SERPENTINE OF THE PIEDMONT

Before taking up the study of the serpentine areas of Harford County it will be necessary to see what relations they bear to the serpentine areas found elsewhere in the Piedmont. Following a summary of the distribution of the serpentine north and south of Maryland, will be given a general discussion of the Maryland serpentines. There has been much confusion caused by the fact that both the mineral and the rock are known by the same name. The origin of serpentine has long been in dispute and in order to take up the study of this area it will not be out of place to give a resumé of the various theories proposed. Since serpentine may originate from the alteration of different minerals, it is not improbable that the different serpentines of this area have originated from different rocks. In working up the literature of the serpentines of the Piedmont belt it was found that different writers have traced the origin of the various localities to different original rocks. Since the serpentines of Maryland are apparently of the same general nature as those of other parts of the Piedmont area, if it is true that these have originated from different rocks, it will be necessary to examine the Maryland serpentines and see if they too may be ascribed to the alteration of more than one kind of rock.

AREAS NORTH OF MARYLAND

STATEN ISLAND

The serpentines forming the main range of hills on Staten Island[4] extends from New Brighton to a little west of Richmond, a distance of 8 miles. The serpentine body must be of considerable thickness for in a well near Stapleton[5] it was encountered at a depth of 50 feet below the surface underneath a covering of drift. The boring extends through 150 feet of serpentine without passing through it. In this area the color of the rock varies from a light-green to nearly black and the texture from compact to earthy. There have been various theories expressed as to its origin. Dr. N. L. Britton[6] in 1881 said that he considered the theory that it was derived from a highly magnesian limestone as the one most in accordance with the facts observed. In a later paper[7] the same author says that he now regards them as derived both from limestones and "hornblende, or rather tremolite," strata. There is no proof, he says, of its being a metamorphosed igneous rock. Newberry[8] regarded it as a pseudomorphic condition of a hornblende slate; Julien,[9] that it is derived from a hornblende schist as it contains fragments of altered amphibole. Britton says that this rock differs from the Baltimore serpentine described by Williams, in that there are no olivine fragments and that there is evidence that it was derived from stratified rocks since the strikes and dips are approximately parallel to the neighboring gneiss which the serpentine overlies. The limestones occurring near this area are parallel to it, or nearly so.

NEW JERSEY

Serpentine occurs in several places in New Jersey. Just north of Hoboken[10] it outcrops along the river bank and rises to a height of from

[4] Merrill, George P. Ann. Rept. Smithson. Inst., 1886, pt. 2, p. 367.
[5] Trans. N. Y. Acad. Sci., 1881, vol. i, p. 56.
[6] Britton, N. L. "On the Geology of Richmond Co., New York." Annals of the N. Y. Acad. Sci., 1881, vol. ii, p. 166.
[7] Trans. N. Y. Acad. Sci., 1886, vol. vi, p. 12.
[8] Newberry, J. S., Trans. N. Y. Acad. Sci., 1881, vol. i, p. 57.
[9] Julien, A. A., Ibid.
[10] Cook, George H. Geology of New Jersey, 1868, pp. 325–326.

40 to 50 feet above tide at Castle Point. The outcrop is not more than half a mile in length along the river and from 200 to 300 feet wide, covering an area of about 30 acres. From Castle Point the outcrop descends rapidly both to the north and to the south and is soon covered by the surficial deposits. That it extends considerably farther south is known, for it was found near the end of the Long Dock, Jersey City, at a depth of 179 feet. It is probable that this is part of the same formation which is seen in Staten Island and which extends along the western border of the gneiss from one place to the other. At Hoboken it rests upon the gneiss rocks which outcrop farther south.[11] The serpentine here contains chromic iron in small grains.

At Montville,[12] in Morris County, occurs a deep-green and oil-yellow, often translucent serpentine associated with a massive and coarsely crystalline dolomite. It occurs principally in nodules of a few inches[13] up to 1 or 2 feet in diameter, or as a thin coating on boulders up to 8 or 10 feet in diameter. Merrill says in conclusion[14]: "The Montville serpentine is a highly hydrous variety, approaching retinalite in composition, and was derived by a process of metasomatosis from a mineral of the pyroxene group with the optical and chemical properties of diopside. This change has been accompanied by a considerable increase in bulk, and in most cases the production of beautiful slickensided surfaces, and a platy structure due to pressure. The excess of lime has recrystallized chiefly as granular calcite of a light bluish tinge, and also in fibrous forms . . . .

No free silica in the form of chalcedonic veins, such as are an almost universal accompaniment of altered beds of dunite, have been found. It is inferred that sufficient magnesia must have been furnished from other sources to convert the whole into serpentine, or that further search will bring to light secondary silicate minerals. . . . ."

[11] Russell, I. C. "On the Geology of Hudson Co., N. J." Annals of N. Y. Acad. Sci., 1882, vol. ii, pp. 30, 31.

[12] Merrill, George P. "Building and Ornamental Stones in the U. S. National Museum." Rept. Smithson. Inst., 1886, pt. 2, p. 366.

[13] Merrill, George P. "On the Serpentines of Montville, New Jersey." Proc. U. S. Nat. Mus., 1888, vol. xi, p. 105.

[14] Merrill, George P. Ibid., p. 110.

Serpentine occurs also at Split Rock, in Morris County; at Franklin, in Sussex County; at Phillipsburg and Jenny Jump Mountain, in Warren County; and at Wenoque, in Passaic County.[15]

DELAWARE

In Delaware[16] a limited body of serpentine occurs 6 miles northwest of Wilmington, and a similar vein near where the Brandywine River enters the state. Traversing the first area is a vein of pegmatite from which much pure feldspar has been obtained. The ridge has a length of about 1 mile and a width of from one-third to one-half mile.

PENNSYLVANIA

In Pennsylvania the serpentine areas have been well mapped and there are numerous references to them in the reports of the Geological Survey. They occur in the counties of Northampton, Montgomery, Delaware, Chester, and Lancaster, all in the southeastern part of the state.

Northampton County

In Northampton County, just north of Easton, there is a ridge of hornblendic gneiss with a maximum elevation of 700 feet above tide and with a general strike of N. 60° E. This gneiss is very dense and has distinct bedding planes with a dip of from 40 to 60 degrees to the southwest. Interstratified with the gneiss are bands of calcite and dolomite of from 5 to 30 feet in thickness. In some places tremolite, phlogopite, and occasionally pyroxene, occur in such quantity as to nearly or entirely replace the carbonates, leaving almost a pure tremolite rock. Professor F. B. Peck[17] says of them: "The explanation of the occurrence here of beds of tremolite would seem to be simple. In the first place the post-Algonkian dolomites are more or less siliceous. . . . .

"Immediately below them come beds of carbonates which are usually

[15] Geology of New Jersely, Final Rept., 1889, vol. ii, pt. 1, p. 18.

[16] Booth, James C. Mem. Geol. Survey Del., 1841, pp. 13; 34–35.

[17] Peck, F. B. "Preliminary Notes on the Occurrence of Serpentine and Talc at Easton, Pennsylvania." Annals N. Y. Acad. Sci., 1901, vol. xiii, p. 420.

highly dolomitic. . . . . Underlying these in turn are the pre-cambrian gneisses which with their included quartz lenses and granite intrusions could furnish free quartz enough by infiltration to transform the beds of carbonates over into silicates of lime and magnesia. . . . . This process of transformation was doubtless greatly facilitated by dynamical forces resulting from faulting, as well appear later. . . . ." Farther on (p. 423) he says: "The serpentines and talcs *are all of them associated with a system of faults* (the italics are mine) which follows the trend of the ridge. Within a distance of two miles north and two miles south of Easton there are four distinct thrust faults. . . . .

"The first of these faults extends along the northwestern side of Marble Mountain and Chestnut Hill and constitutes the boundary line between the pre-cambrian and the post-Algonkian." Branching off from this is another fault which runs along the southeastern slope of Chestnut Hill. "It is along this branch fault . . . . that all the talc and serpentine deposits or the region, with one exception, occur. . . ." Even this exception is described as occurring along another fault.

Continuing, Professor Peck says: "All of the rocks involved in the faulting are so sheared, stretched, and profoundly altered as often to be recognized with difficulty. . . . . The hornblende alters for the most part to serpentine, in fact the richly hornblendic granites seem to furnish one source of serpentine. The calcite-dolomite beds shear to a slaty, foliated, talcose mass. . . . . *Phlogopite*, (again italics are mine) which is locally developed in large quantities in connection with these beds, sometimes in huge crystals a foot in diameter but usually in rather finely granular masses, alters quite uniformly to serpentine and *constitute the chief source of that mineral in the Easton quarries.* Huge masses of it weighing many tons are removed from time to time, consisting quite wholly of phlogopite mica in different stages of alteration to serpentine. . . . . (William's) quarry has been excavated in a nearly pure tremolite rock which lies in heavy beds nearly 50 feet thick and dipping south under granite. . . . . Evidently this rock has been faltered [faulted] into its present position. . . . . The shearing to which it has been subjected has partially altered the tremolite to talc

along the shearing planes. . . . . Scattered through this finely crystalline, sometimes massive white tremolite rock, are seams and irregular aggregations of what was originally phlogopite or pyroxene, now altered thoroughly to a beautiful apple-green serpentine. . . . . ."

Merrill,[18] writing of the same area, compares the serpentine with that of Montville New Jersey, and suggests that the association of the serpentine with the white tremolite rock indicates its genetic relationship. He does not discuss the origin of the tremolite, but says that there is a gradual transition of the white tremolite to a rock composed of serpentine, tremolite, and calcite, sometimes within a distance of a few inches. As serpentinization continues the tremolite is broken up into fibrous aggregates cut through by the serpentine with but little regard to the cleavage lines.

Montgomery County

In Montgomery County[19] are several lines of serpentine outcrops a couple of miles south of the town of Conshohocken, and extending from Bryn Mawr to Chestnut Hill. As mapped by the Pennsylvania Survey there are some 18 areas, the longest of which is about a mile in length and from 400 to 500 feet in width. Bascom[20] says of the Chestnut Hill area of Montgomery County, that the serpentine was derived from olivine and not from a dolomite or an enstatite rock. The dark-green crystals which are often twinned, are speudomorphs after olivine. This serpentine lies wholly within the mica-schists southeast of the precambrian gneiss.

In the Lafayette belt[21] in a quarry is an enstatite-like rock which appears to be the rock that is here altered to serpentine, for one bed can be seen to be enstatite below and serpentine above. The country rock of Montgomery County is micaceous schist and gneiss. In Lower

[18] Merrill, George P. "Notes on the Serpentine Rocks from near Easton, Pennsylvania." Proc. U. S. Nat. Mus., 1889, vol. xii, p. 599.

[19] Second Geol. Survey Pa., Rept. X, 1885, p. lxxxi; Rept. C6, 1881, p. 26.

[20] Bascom, F. Proc. Cad. Nat. Sci. Phila., 1896, p. 219.

[21] Second Geol. Survey Pa., Ann. Rept. for 1886, pt. 4, p. 1608.

Marion township the bounding rock of a steatite belt is distinctly garnetiferous mica schist to the north.[22]

Rogers[23] says of the origin of the magnesia of the soapstone which extends east from the Wissahickon on the brow of Chestnut Hill across the Schuylkill to Mill Creek beyond Merion Square: "Viewing the steatite as a stratified rock of the mica-slate group, we may reasonably regard it as having been metamorphosed to its present composition and structure, by infusion of magnesian matter from the dyke of intrusive Serpentine which everywhere adjoins it."

Delaware County

In Delaware County[24] a serpentine belt extends entirely across the county. There are mapped some 65 or 70 areas by the Second Geological Survey, the majority of which are not more than a quarter of a mile in length; the longest area being about $2\frac{1}{4}$ miles. The serpentine occurring in the central part of the county, extending from about 9 miles from Rockdale to Darby Creek, has been quarried for building material. The outcrops are all approximately parallel and are in what is called by Hall of the Pennsylvania Survey, the "Chestnut Hill schist area," and, according to him, apparently belong to the upper part of that series. He says of it[25]: "The Delaware County deposits demonstrate the fact, that the serpentine areas are shallow synclinal basins, many of them saucer-shaped. . . . .

"I think that there is no question that the steatite belongs to the same horizon as the serpentine. . . . ." All the serpentine through this region (Delaware and Montgomery counties) belongs to the same geological horizon, "but it is safe to assume that the serpentines are one of the most recent deposits."

[22] Second Geol. Survey Pa., Ann. Rept. for 1886, pt. 4, p. 1607.
[23] Rogers, Henry D. Geology of Pennsylvania, 1858, vol. i, pp. 71–72.
[24] Second Geol. Survey Pa., Atlas X, 1885, p. xlvii.
[25] Second Geol. Survey Pa., Rept. C5, 1885, p. 13.

An analysis of the serpentine from Mineral Hills gives:[26]

Moisture expelled at 110°	2.10%
Loss on ignition	12.78
Silicic acid	44.18
Alumina	tr.
Ferrous oxide	1.64
Magnesia	39.37
	100.07

Associated with the serpentine of Delaware County are beds of impure limestone, pure kaolin, and corundum. Fine crystals[27] of corundum weighing several hundred pounds have been found[28] in several places. The corundum occurs with the feldspar of which extensive mines have been worked in the western part of the county.

T. C. Hopkins,[29] in a paper read before the American Association for the Advancement of Science at the Boston meeting, on "Some Feldspar in Serpentine from Southeastern Pennsylvania," said that the feldspar of this district occurs in veins or dykes, often attaining a thickness of 20 to 25 feet. The feldspar varies from white to pink, and appears to be entirely orthoclase. In Chester County the mines are also near the corundum mines.

Chester County

The largest veins of serpentine in Pennsylvania are found in Chester County. There are some 24 or 25 areas, all of which seem to occur on the south side of the hydro-mica slate belt and the feldspathic micaceous gneiss belt.[30]

"Whatever may be the age of the rocks of this region," says Frazer[31] in speaking of the gneiss belt, "they were originally sediments of mud, sand, and gravel, for they are everywhere more or less distinctly strati-

[26] Second Geol. Survey Pa., Rept. C5, 1885, p. 120.
[27] Ibid, Rept. C4, p. 37.
[28] Ibid., Rept. X, p. xlvii.
[29] Hopkins, T. C. Amer. Geol., 1898, vol. xxii, p. 256.
[30] Second Geol. Survey Pa., Rept. C4, 1883, p. 62.
[31] Ibid., p. 37.

fied. . . . . Even were we sure of the relationship of the limestones and serpentines to the schists and gneisses, they would not be quite available as key-rocks, because they seem to be of more or less local origin; and even where they appear to underlie the surface in continuous lines or belts, they are only occasionally visible in or above the soil."

Of the soapstone he says: (p. 52) "The soapstone (steatite) strata on the Schuylkill are only mica slate beds with the mica wholly replaced by talc. . . . . "

The second area in size is the one south of Paoli. This has a length of about 6 miles. Of this Rogers[32] says: "Its course is W. about 25° S., coincident nearly with that of the strike of the gneiss and talcose slate which border it for the greater part of its length. . . . . Beyond Maris's Grist Mill its total breadth is nearly 2000 feet . . . . northeast of East Goshen Friends' Meeting-house . . . . a breadth of no more than 400 or 500 feet . . . . . Throughout its entire range, this serpentine appears chiefly as a stratified rock, and in its widest central portion we may distinctly perceive that it has a synclinal or indulated structure. It is, indeed, rather an impure talcose slate, largely impregnated with serpentinous matter, than a zone of genuine intrusive serpentine. . . . ."

The eastern end of this zone of serpentine is bordered both south and north by the talcose-slate formation, in which it seems to lie as a folded synclinal trough; but from the vicinity of Maris's Grist Mill to its western termination, its southern margin is in contact with a massive hornblendic gneiss, its northern touching in some places upon ordinary talcose slate; but in others, especially towards the western end, upon quartzose and garnetiferous micaceous gneissoid rock. . . . .

Along the northern edge, or a little outside of the northern margin of this line of serpentine, trap-rock occurs in greater or less abundance, and apparently as a succession of narrow elongated dykes. . . . . "

An analysis by S. B. Sparkler[33] of a specimen from East Goshen shows the following:

[32] Rogers, Henry D. Geology of Pennsylvania, 1858, vol. i, p. 168.
[33] Amer. Jour. Sci., (2), vol. xlii, 1866, p. 272.

SiO_2	32.89%
Al_2O_3	—
Fe_2O_3	—
FeO	1.38
CaO	—
MgO	40.48
MnO	—
H_2O	13.45
	99.20

The specific gravity is given as 2.72.

Along the boundary line between Pennsylvania and Maryland and extending from the center of the southern part of Chester County along the southern part of Lancaster County southward into Cecil County, Maryland, and thence across the Susquehanna River into Harford County, is the tract known as the "State Line serpentine." Its length is about 17 miles from Elk Creek to the Susquehanna. It has a mean width of about 1 mile. The Pennsylvania Survey[34] says that the southern margin is in contact with the black hornblende gneiss, but the serpentine is apparently without conformity of dip on the Susquehanna; the rock to the south is a talcose slate.

On the north throughout its entire length the bounding rock is the talcose slate of the Primal series. "Much trap rock presents itself just west of the Little Elk along the southern edge of this range of serpentine, and dykes of that material occur within and adjacent to the belt, especially throughout its southern half, and apparently along its whole course."

In the same report, in speaking of the chrome ore which occurs with this serpentine body, the statement is made that the chrome ore occurs in the serpentine as true ore veins, cutting through it with considerable regularity. For some time the State Line serpentine was the source of most of the chromium in the United States.

The serpentine of this region is regarded by most of the writers as of two kinds. In speaking of the serpentine near Morgan Corners, Rogers says:[35] "The belt of serpentine comprises both true injected or

[34] Second Geol. Survey Pa., Rept. C4, 1883, p. 91.

[35] Rogers, Henry D. Geology of Pennsylvania, vol. i, 1858, p. 163.

igneous serpentine, and *serpentinous steatitic talc-slate.*" Again in speaking of the West Chester Barrens: (p. 169) "[These] exposures of serpentine and steatite occur so nearly in one line, and this is so probably a line of dislocation connected with the synclinal fold of the older strata, that we can hardly doubt that these outcrops derive their existence from one chain of injections of true serpentine mineral along the southern margin of the talcose Primal slates."

Throughout his article Rogers makes particular mention of the fact that there are two kinds of serpentine, "stratified serpentinous talc-slate" and "injected or infused true igneous serpentine."

Theodore D. Rand[36] in 1896 before the Academy of Natural Sciences of Philadelphia, said that he regarded the serpentine of southeastern Pennsylvania as belonging to all least two groups, "one bordering the ancient gneiss; the other, which he believes to be much more recent, occurring in the mica schist and gneisses.

"The former are altered igneous rocks, either pyroxenic or crysolitic, the chief material being enstatite, found often but slightly altered; the latter of more doubtful and perhaps varied origin. . . . .

"The bright yellow serpentine from Easttown Township, Chester Co., is probably altered chrysolite chiefly, while that from Fritz Island, near Reading, is an altered dolomite. That from Brinton's Quarry, near West Chester, contains bronzite, not entirely changed.

"The Radnor serpentine is chiefly an altered enstatite but . . shows, also, a change from asbestos into serpentine. . . . ."

Persifor Frazer[37] summing up the various theories of the origin of the serpentine of this region, says:

"Were these [serpentine exposured] ranged in more than one line the task of explaining their appearance at the surface would be much easier. But a *single line* of them necessarily places them either at the top or at the bottom of the talc-mica schist formation; Mr. Hall choosing the former, Mr. Rogers the latter alternative.

"The case is complicated by the fact that the outcrops along this one

[36] Proc. Acad. Nat. Sci. Phila., 1896, p. 219.
[37] Second Geol. Survey Pa., Rept. C4, 1883, p. 84.

line are sometimes serpentine, and sometimes limestone. It looks as if the serpentine might be a subsequent modification of the limestone; or else, that one and the same magnesian sediment was heavily charged with carbonate of lime in some places, and was a non-calcareous silicious mud in others.

"It would of course be possible for the two species of rocks to have no connection . . . . if they were sporadic deposits at very nearly but not quite the same geological horizon; . . . .

"If Mr. Hall's structure be accepted, if the talc-mica belt be Hudson river slate, then this serpentine limestone range would represent the Upper Siliurian calcareous deposits.

"If Mr. Rogers' structure be accepted, if the talc-mica belt be primal slates passing northward underneath the Potsdam sandstone, and Valley limestone, then the serpentine range can have nothing to do with the Valley limestone formation."

Corundum has been found in many places in Chester County. Colonel Joseph Willcox[38] says of it:

"Many large lumps were formerly lying on the surface of the ground, and vain efforts were made to drill holes in them for the purpose of blasting them. A final disposition was made of them by digging holes near them, in which they were buried deeply enough to cause no interference with the plow." In 1848 a lump weighing more than 5200 pounds was sent to Liverpool. In 1866 John Leslie dug up about five tons which he sold for $60 per ton, but soon after the price advanced to 50 cents per pound. In 1872 a mass weighing about 200 tons was found on the margin of the serpentine bed against a wall of gneiss rock on the north side. Associated with it were margarite, damourite, and lesleyite; in other places associated with tourmaline, albite, and spinel.

On page 351 of the same volume Persifor Frazer says: "It is evident that the *corundum* . . . . is a metamorphosed part of the gneiss composed more exclusively of alumina than the rest."

[38] Second Geol. Survey Pa., Rept. C4, 1883, p. 349.

Lancaster County

The State Line serpentine area continues westward into Lancaster County. The rock has been penetrated to a depth of 700 feet in the chrome mines without passing through it. At several places in this belt titaniferous iron ore has been mined. Roger[39] says: "A careful examination of these . . . . belts of serpentine near the State line of Lancaster County cannot fail to convince any observant geologist that the material, ordinarily termed serpentine, as presented in these barrens, comprehends both a stratified and a unstratified rock. Pure serpentine is here found only in the form of dykes intruded through a stratified serpentinous talcose rock, evidently a metamorphic clay-slate—the mica and talc-slate formation of the Susquehanna. The stratified serpentinous rock seems to have been impregnated with the magnesian minerals during the intrusion of these veins of igneous serpentine. The evidences in support of this view are abundant in the ravines which intersect the barrens north of the village of New Texas. The genuine serpentine rock is itself a material of quite diversified aspect, some of it being of a dark-green color, and very tough; other varieties less dense and heavy, and much more easily fractured, and of a pale or yellowish green. This latter kind usually abounds in contact with the chromiferous iron-ore at Wood's Mine and the other chrome localities. . . . ."

Besides this State Line area there is but one more of any size in Lancaster County. This is situated to the northwest of the former and is about 5 miles in length. The outcrop is of an irregular shape, the two ends run nearly north and south and are connected by an east and west area.

AREAS SOUTH OF MARYLAND

VIRGINIA

Information on the serpentine of Virginia is meager. In Rogers' report[40] he says that in Albemarle County there is a tough, somewhat

[39] Rogers, Henry D. Geology of Pennsylvania, 1858, vol. i, pp. 171, 172.
[40] Rogers, W. B. Reprint of the Geology of the Virginias, 1884, pp. 296–297.

soft rock of a bluish-gray color occurring between two ranges of sandstone. This rock is steatitic and is associated with talcose and other strata. It is uniform in texture and capable of being worked. From Albemarle County it runs southwest, increasing in width and becoming more serpentinous. In Nelson County it occurs west of Ligons and the greater part of it is serpentine. On the same line it occurs in Amherst County at the base of Buffalo Ridge as a narrow belt and contains copper ore. Farther south, near Lynchburg, it crosses the James River but here contains but little serpentine. Continuing southwestward there is soapstone in Franklin County but still farther south these talcose rocks thin away.

In Fluvana and Louisa counties (Idem., p. 463) soapstone, unmingled with serpentine, extends with variable width nearly in the direction of the county line between Mechanicsville, and Newark. In Fairfax County both soapstone and serpentine occur, but the principal rock is serpentine. Between Difficult Creek and, Still House Branch both occur and here also chrome ore is associated with it.

NORTH CAROLINA

South of Virginia the olivine rocks are less serpentinized. In North Carolina the prevailing type is dunite and the rocks have been subjected to alteration in but few places.[41] Associated with these rocks in North Carolina, South Carolina, Georgia, and Alabama is corundum and chromite. These magnesian rocks extend over a wider area in North Carolina than in any of the other states of the Piedmont belt. The rock, in numerous disconnected outcrops, is spread over an area 40 miles wide. With the exception of a small area in Clay County, there is no serpentine south of Waynesville. It is rather remarkable that the region south of Waynesville is thickly dotted with small peridotite areas while north of the village the areas are rather scattered and few, yet among all these southern areas none is serpentinized. In Buncomb, Madison, and Yancey counties the granular rock is largely

[41] Lewis, J. V. "Corundum and the Basic Magnesium Rocks of Western North Carolina." Bull. 11, N. C. Geol. Survey, 1896, p. 33.

changed to serpentine, and the microscope shows that it is altered olivine rock. Magnetite and chromite are associated with it. In a serpentine found on Ivy River in Madison County, there remains a large percentage of unaltered olivine "in some cases visible to the naked eye."[42] Most of the serpentine is similar in appearance to that of Maryland and Pennsylvania. Pratt gives as a proof of the igneous origin of the peridotite the fact that at Webster, Jackson County, "a large block of gneiss is completely enclosed by the peridotites in such a manner as could only be attributed to the intrusion of the latter in a molten condition."[43]

SOUTH CAROLINA

The reports on the geology of South Carolina that have been examined are all of them of old date and I have been unable to find reference to any recent work. The latest map that I have seen is that published by the Department of Agriculture in 1883 and on which are shown areas of soapstone in Kershaw, Fairfield, and Richland counties, all of them a short distance north of Columbia; and in Laurens, Pickens, and Spartenburg counties in the extreme western portion of the state. Tuomey[44] in his report for 1848 speaks of "talcose-slates" as composed chiefly of talc and quartz and sometimes of talc and feldspar; but these can hardly be classed with serpentines or soapstones. Associated with the talc-slates are mica-slates. These are found in passing (p. 74) "by insensible degrees, into talcose-slates, by the substitution of talc for mica; when both minerals are found in the same rock it is called talco-micaceous slate. This and the talcose slates are confined to that portion of the state known as the gold region, and to the belt in York and Spartanburg that contains the magnetite iron ores. The finest specimens of talcose slate are found near Cherokee Ford, associated with the ores of that locality, and at Hale's mine, in Kershaw. In Lancaster it passes into talco-micaceous slate, which is the gold bearing rock of the district."

Farther on (p. 106) he says: "A strip of talco-micaceous slates of the

[42] Pratt, Joseph Hyde. "The Occurrence, Origin and Chemical Composition of Chromite." Amer. Inst. Min. Eng., Trans., 1899, vol. xxix, p. 20.

[43] Pratt, Joseph Hyde. Idem., p. 31.

[44] Tuomey, M. Rept. on the Geology of S. C., 1848, p. 9.

gold formation, crosses the north-west corner of the (Edgefield) District on the Savannah. . . . .

"Near the Newberry line (Newberry District) and midway between the Saluda and Broad River, is an elevation . . . . principally composed of mica and talcose slates. . . . . Near the mill the slates . . . rise up on the side of the mountain, being pushed into a position nearly vertical—the bedding planes so straight and even as to present smooth surfaces where the rock is split, and often so hard as to offer inducements for opening a quarry for flagging stones for pavements. . . . ."

A few miles from Chester is a bed of soapstone which has been slightly worked. Lieber[45] speaks also of the talcose slate. He says: "The talcose slate . . . . embraces several disconnected bodies, which are mostly separated from one another by granitic rocks. . . . . It stretches between the granite of the Waxhaws and the granitic and syenitic dyke of Taxehaw over the main portion of Lancaster, from which district it passes into Chester, terminating about two miles east of the Charlotte and South Carolina Railroad. . . . . Here it touches the gneiss of West Chester, while to the north and south it is bounded by mica slate, the result apparently of a contact metamorphosis.

"A metalliferous country rock the talcose slate occupies, with us, a most prominent position, and in reference to gold, at least as far as I have been able to observe, it stands highest in the scale. . . . ."

"Soapstone shows itself in some parts of York and Chester. The large dykes are usually impure, and often form a species of porphyry in which the imbedded crystals are hornblende. When the grain of it is fine it is termed a talcose of chloritic trap. At the Nation Ford of the Catawba in York, and immediately north of Chesterville, soapstone of a fine quality is quarried." (p. 36)

GEORGIA

In Georgia all the corundum deposits occur in veins intersecting the peridotites and their alterations,[46] but no perfect serpentine has as yet

[45] Lieber, Oscar M. Report on the Survey of South Carolina, 1856, p. 22.
[46] King, Francis P. Bull. 2, Ga. Geol. Survey, 1894, p. 75 et seq.

been found in any part of Georgia although there are some partially serpentinized chrysolites. These basic magnesian rocks in this state are usually small areas stretching across "like a string of beads with here and there a missing member" as described by King. Most of these eruptive rocks are west of the Chattahoochee River and near the semi-crystalline boundary, in which, however, none occurs. King calls these rocks the youngest of the Algonkian crystallines (p. 71).

ALABAMA

In Alabama asbestos has been found in Coosa and Tallapoosa counties near the corundum mines. Corundum, associated with peridotites, has been found near Dudleysville, Tallapoosa County, and near Bradford in Coosa County.[47] Talcose rocks, and beds of hornblende and soapstone occur on the Tallapoosa River near the falls.[48]

AREAS IN MARYLAND

The serpentines in Maryland were early known because of the association with them of the chrome ores, which for a long time formed the principal source of chrome in the world. Chrome was first discovered in America at the Bare Hills, north of Baltimore, on the property of Isaac Tyson. Tyson's son soon started in to manufacture chrome yellow from this material. In the same year he recognized, in a stone which was used to support a cider barrel in Belair market, a valuable piece of the ore. This led to the purchase by him of considerable areas in Harford County, near Jarrettsville, where this fragment had been obtained. The opening of the mines here showed so great an abundance of the material that it was found more profitable to work than at the Bare Hills, consequently the latter workings were abandoned. Tracing the occurrence of chrome by its association with serpentine, Tyson in 1833, discovered the deposit on the Wood farm in Cecil County and at once purchased the property. This proved to be the richest chrome deposit ever found in America, and was worked with great success until

[47] Smith, Eugene A. Outline of the Geology of Alabama. 1878, p. 19.
[48] Smith, Eugene A. Bull. 3, Geol.Survey Ala., 1892, p. 84.

about 1881, with the exception of from 1868 to 1873. Chrome ore had been discovered in Asia Minor in 1848, and early in the eighties it was found that the foreign product could be imported cheaper than the domestic product could be mined, consequently the Maryland workings were abandoned.

The areas of serpentine and soapstone stretch across Maryland in a series of lenticular masses similar to those of Pennsylvania, and occur in Cecil, Harford, Baltimore, Carroll, Howard, and Montgomery counties. All of these rocks are plainly of secondary origin, being derived from the non-feldspathic magnesian rocks—peridotites and pyroxenites. In general the direction of these lenses is that of the strike of the neighboring gneisses and phyllites. The dip, where it can be made out, varies from 40 degrees to nearly vertical.

CECIL COUNTY

Ducatel,[49] in his report for 1837, speaks of the occurrence of a good quality of soapstone on the west branch of the Northeast River. The material was quarried for stepping stones. At New Leeds and on the County line between the Octorara and Conowingo, asbestos and talc are mentioned as occurring, being used in the manufacture of "stone points," a substitute for metallic pigments made by grinding up the soft and light-colored varieties in whale oil. He also mentions the use of asbestos as a lining for fire-proof chests and speaks of the occurrence of chrome ores in the county.

F. Bascom[50] writes as follows: "For five-eights of a mile from the northern limit of the gabbroic material to Bald Friar, the Susquehanna cuts through a belt of soft and sometimes soapy greenstones.

"These greenstones represent various phases in the metamorphism of non-feldspathic igneous rocks. This belt widens to the northward and, with a width on the Mason and Dixon Line of three and one-eighth miles, passes, north of Rock Springs into Pennsylvania, where it trends

[49] Ducatel, J. T. Ann. Rept. Geologist of Md., 1837, p. 15.

[50] Bascom, F. "The Geology of the Crystalline Rocks of Cecil County." Md. Geol. Survey, Cecil Co., 1902, p. 93 et seq.

to the east and sweeps southward into Cecil County at four points between Rock Springs and Fair View. The last exposure is some sixteen and a half miles east of the Susquehanna river. The two more easterly of these occurrences are disconnected at the surface from the main mass by gabbro.

"The greater portion of this ultrabasic material has undergone complete alteration to serpentine. So thorough is the transformation throughout the mass of the formation that the original characters of the rock may only be determined by microscopic study.

"At scattered localities along the southern periphery of the serpentines, gradations into only partially altered pyroxenites and peridotites may be observed in the field. Such passage into well-recognized pyroxenites and peridotites is also exhibited in the dykes . . . . and in the lens-shaped included masses. . . . . The serpentine is most varied in color and general appearance. It ranges in tint from a light buff, or a light yellowish green, to a rich, deep emerald or a dark blue green.

"Where the serpentine possesses a soft earthy texture, the colors are usually light in tint. Where it is compact and massive there is a deepening of the green tones, while a schistose or fibrous character is associated with a greyish green shade, which is due to the development of either talc, asbestos or tremolite.

"The rock possesses no original structural planes, but exhibits more than one system of secondary planes produced by pressure acting upon a massive rock. The master-joints are nearly vertical and strike northeast and southwest. The joint faces are often slicken-sided.

"The metamorphism of the original ferromagnesian silicates (pyroxene, amphibole and olivine) into the hydrous magnesian silicate, serpentine, is accompanied by the liberation of iron oxides and silica, in the form of hematite or limonite and quartz or opal, or a yellow limonitic jasper or chalcedony.

"The ground is strewn with these rusty yellow silicious iron-stones, which exhibit more or less of a honey-comb structure due to a finally complete removal of the magnesian silicate.

"Serpentine is always accompanied and is sometimes completely

replaced by a final alteration product talc (steatite, soapstone). Soapstones are therefore also of frequent occurrence in serpentine areas.

"With the serpentines are also associated amphibole schists containing asbestos, tremolite, anthophyllite, actinolite or chlorite, and representing the metamorphism of pyroxenites. All these associated types, the original peridotites and pyroxenites, the serpentines representing one phase of metamorphism, the amphiboles representing another phase of metamorphism, the soapstones and the iron-stones representing an extreme phase of alteration, are considered a geological unit and mapped as a single formation. . . . .

"The main serpentine belt is locally known as "the barrens" and strikingly merits that name. At the border of the serpentine belt the aspect of the country alters abruptly. One leaves behind a prosperous and pleasing agricultural region and enters a wild and desolate district supporting a scanty vegetation. . . .

"The comparative sterility of the soil may be due to its thinness and inability to hold water rather than to its chemical composition. . . . .

"In the serpentine as in the mica-gneiss there are phematite veins. Some of these are of considerable size and have been opened for the feldspar.

"The veins usually, but not always, strike northeast-southwest.

"There are a number of abandoned openings for feldspar in the region of Goat Hill. . . . . Three-eights of a mile east of Rock Springs, are two feldspar openings in a vein some six to eight feet wide, which have been abandoned for three years. . . . . The serpentine bordering the vein has altered to talc. . . . .

"About one and a half miles east from Rock Springs, on the edge of the serpentine is the Taylor feldspar and flint quarry. This vein strikes northeast-southwest and has considerable width. . . . .

"Magnesia has also been mined in the serpentine, but only in small quantities. . . . . On the roads from Conowingo to Rock Springs and from Conowingo to Pilot, there are pits in the serpentine made in search of gold ore . . . . with the expectation of finding the rocks richly auriferous. The results did not meet their expectations. . . . ."

An analysis is given (p. 133) of a pyroxenite of the variety websterite.

SiO_2	53.21	RECALCULATION.	
Al_2O_3	1.94	Hypersthene	43.72
Fe_2O_3	1.44	Diallage	55.97
FeO	7.92	Misc	.79
MgO	20.78		
CaO	13.12		100.48
Na_2O	.11		
K_2O	.07		
H_2O+	.87		
H_2O-	.14		
CO_2	.10		
TiO_2	.26		
ZrO_2	trace		
P_2O_5	"		
Cl., F	undet.		
FeS_2	.03 (0.02 S.)		
Cr_2O_3	.20		
NiO, Co O	.03		
MnO	.22		
BaO	none		
SrO	"		
Li_2O	trace		
V_2O_3	.03		
Total	100.47		

Analysis made by W. F. Hillebrand, of the United States Geological Survey. Amer. Geol., vol. xxviii, 1901, p. 159.

Bascom says further (p. 134): "Massive serpentines more generally disclose a peridotitic origin, but even the earthy serpentines show remnants of original olivine. The fibrous serpentines exhibit remnants of tremolite and other fibrous amphiboles by means of which their origin can be traced by pyroxenites.

"Serpentine possesses a more uniform appearance under the microscope than in the hand specimen. Faintly green, transparent sections, showing in polarized light a confusedly fibrous character and mesh structure, with olivinic cores and an occasional crystal of pyroxene or tremolite, are a common type of earthy or massive serpentine. . . . ."

"A preponderance of tremolite, anthophyllite or smaragdite characterizes the fibrous serpentines. Tremolites may still show a central area or core of pyroxene.

"Talc is a common secondary product both in the fibrous and massive serpentines. It may completely replace both serpentine and amphibole, converting the rock into a soapstone or a steatite-schist. . . . .

"The change of talc to the fibrous amphiboles is accompanied by the separation of calcite or dolomite which fills the interstices of the talc. . . . .

"The origin of serpentine and soapstone from pyroxenites and peridotites is a well recognized fact, and the occurrence of serpentines with such a genesis . . . . has been described."

HARFORD COUNTY

J. T. Ducatel,[51] in 1838, speaks of the occurrence of the chrome ores associated with the serpentine in the vicinity of Coop Town and "Mine Old Field," and near Dublin. "This *Chrome ore*" he says, "is always found imbedded in a rock, called the *Serpentine*, which latter also contains a variety of *Magnesian minerals*. . . . . Associated again with these minerals, there are varieties of *Asbestos*, that within a few years have come to be extensively used in the manufacture of what are called *Stone paints*. . . . . "

Tyson,[52] in 1862, speaks of the occurrence of chrome ore in Harford County, the working of the pits near Cooptown, and their abandonment for the Cecil County deposits. Associated with the serpentine here he speaks of copper: "Near the northern edge of the serpentine formation north of Cooptown some traces of copper ore, in the form of carbonate of copper, were observed some thirty-five years since. The openings at that point, however, gave no encouragement to those by whom it was explored. . . . . "

Genth[53] in a report on the serpentine of Broad Creek said: "Immediately adjoining and under the talcose rocks, and from them separated

[51] Ducatel, J. T. Ann. Rept. of the Geologist of Md., 1838, p. 5.

[52] Tyson, Philip T. Second Rept. of St. Agricul. Chemist, 1862, p. 65.

[53] Genth, F. A. "Geol. Rept. of the Maryland "Verde Antique" Marble, and Other Minerals on the lands of the Havre Iron Co., in Harford County, Md." 1875, p. 4.

in most cases by seams of chlorite or chlorite-slate, lies a very large bed of green serpentine, presenting, as observed alongside of Broad Creek, a thickness of about 500 feet, and under this a bed of black mottled serpentine of about 800 feet in thickness, and, frequently imbedded in the latter, masses of the above-mentioned green serpentine, increasing in quantity in a north-westerly direction. This immense bed of serpentine in these two varieties rests upon chloritic slates, frequently containing octahedral crystals of magnetite, and talc slates, and below these again occurs another, but smaller, bed of green serpentine of 180 feet in thickness, which, like the other, is underlain by chloritic and talcose slates, and, where Broad Creek makes a westerly turn, followed by a third bed of green serpentine. . . . .

"The 'outcrop' of the first or upper bed of green serpentine of about 500 feet in thickness can be traced by its outcrop almost the whole distance between the upper ford on Broak Creek, and over the hill in a north-easterly direction to the ravine on Broad Creek, a distance of, about 1800 feet; it also crosses Broad Creek in a south-westerly direction, but it has not been ascertained how far it extends.

"The outcrop of the second bed of green serpentine was measured on top of the hill between the horse-shoe of Broad Creek to be about 180 feet, and it is very conspicuous on the west side of Broad Creek; but as neither this, nor the third, are in the least developed, and as their exploration cannot offer any advantages, nothing more need be stated, but that they exist and show throughout the same character. . . . .

"From the present developments, the relation of the magnesian rocks on this property, in their alternate beds of talcose and chlorotic slates and serpentine, to that of the micaceous strata cannot be ascertained with certainty, but they do not appear to be comformable in their stratification and dip, and while the latter have an average strike of about N. 40° E., with a dip of about 30 to 40° toward the south-east, the whole body of magnesian rocks seem to form a large lenticular mass in the micaceous strata, having the same general direction, but an average strike of N. 69° E., with a south-easterly dip of about 75°. . . . .

"This green serpentine . . . . is a variety of massive serpentine

somewhat resembling Williamsite, and shows sometimes a slightly slaty structure. It occurs in various shades of green, from pale leek-green to a deep blackish green, and from a small admixture of magnetic iron, more or less clouded; rarely with thin veins of dolomite passing through the mass. It is translucent to transparent; it is exceedingly tough, and its hardness is considerably greater than that of marble. . .

"The analysis of a deep green translucent variety gave the following result:

Silicic acid	40.06
Alumina	1.37
Chromic oxide	0.20
Niccolous "	0.71
Ferrous "	3.43
Manganous "	0.09
Magnesia	39.02
Magnetic iron	3.02
Water	12.10
	100.00

Hardness 4.00 Specific gravity 2.668

Its green color is due to the oxides of chromium, nickel and iron present

". . . . A black mottled serpentine underlies the green, forming a bed of about 800 feet in thickness. . . . . It weathers more readily than the green, changing into a white rock spotted with black. . . . . The analysis shows it to be a variety of serpentine, like the green, with an admixture of a larger percentage of magnetic iron. It contains:

Silicic acid	40.39
Alumina	1.01
Chromic oxide	trace
Niccolous "	0.23
Ferrous "	0.97
Manganous "	trace
Magnesia	38.32
Magnetic iron	6.22
Water	12.86
	100.00

Hardness 4.00 Specific gravity 2.669"

Merrill[54] gives an analysis of the gray-brown soil into which the green serpentine weathers as follows;

Silica	60.17
Iron oxides	10.40
Alumina	14.81
Magnesia	7.23

This is quite a contrast with the fresh rock which carries nearly 40 per cent of magnesia, and less than one-half of one per cent of alumina.

This Broad Creek quarry is the principal serpentine quarry in Maryland, and the rock produced here is of exceptional beauty. Slabs of large size have been sawn out and polished. The color varies from a rich emerald green mottled with darker patches and streaks to a deep blue-black. The variety is sometimes called precious serpentine although it is hardly transparent enough to be true precious serpentine. The product of the quarry was called "verde antique" although it was not such. Extensive preparations were made for developing the quarry in 1880 but these were not entirely successful. The stone is extremely hard and the expense of working the material and getting it from the quarry is great. A great deal of the stone, has, however, been put upon the market, and it has been used in the interior decoration of buildings in New York, Philadelphia, Washington, Wilmington, St. Augustine, and elsewhere. At the present time the quarry is not in operation and when visited during the summers of 1901 and 1902 it has apparently been abandoned.

Another quarry in Harford County which has placed stone upon the market is the one near Cambria. Samples from this quarry formed a considerable part of the building stone exhibit made by the State of Maryland at the expositions at Buffalo and Charleston in 1901 and 1902.

BALTIMORE COUNTY

The discovery of chrome ore in the serpentines of the Bare Hills north of Baltimore has already been mentioned. Ducatel in his

[54] Merrill, George P. "Rocks, Rock-Weathering and Soils." 18, p. 226.

early reports speaks of this chrome and in 1860 Tyson[55] says of it that "it seems to have been forced in as an intrusive rock in isolated masses of limited areas. . . . . It is slowly acted on by atmospheric agents, and furnishes a barren soil wherever it is the nearest rock to the surface." In the Appendix to the same report (p. 15) he says of the region to the north of Baltimore, that "the district called the Bare Hills, because of its sterility, owing to the large quantity of magnesia in the soil." In 1862[56] he mentions the Soldier's Delight area. "From eight to ten miles west by north from the Barehills is another formation of serpentine called Soldier's Delight. . . . . The only minerals of industrial value it contains are chrome ore and a magnesian mineral; the latter having been used for the manufacture of epsom salts.

"The chrome ore here is similar to that at the Barehills, and continues to be mined to some extent, but operations have not been extensively carried on within either of those formations since they were commenced in Harford County, about thirty years since. . . . . "

The first petrographical study of the Baltimore serpentine was published in 1886 by G. H. Williams[57] in an article on the Gabbros and Associated Hornblende Rocks Occurring in the Neighborhood of Baltimore. In this paper he clearly showed the secondary origin of the serpentines, tracing the origin to the basic non-feldspathic rocks with which they are so often associated. He says: "The olivine-bearing rocks of the Baltimore region exhibit a most interesting and instructive series of alterations, the study of which has satisfactorily established the fact that masses of a similar character were the original form of a varied group of magnesian rocks common throughout the district. . . . "Generally speaking, the olivine of these rocks changes to serpentine and magnetite; the pyroxene, whether bronzite or diallage, alters at first to a light-green or colorless hornblende, having the composition of actinolite or of tremolite. This hornblende in turn is frequently transformed into

[55] Tyson, Philip T. First Rept. St. Agricul. Chemist, 1860, p. 24.
[56] Tyson, Philip. Second Rept., 1862, p. 65.
[57] Williams, George Huntington. "The Gabbros and Associated Hornblende Rocks Occurring in the Neighborhood of Baltimore, Maryland." Bull, 28, U. S. Geol. Survey, 1886, pp. 56–59.

talc, accompanied by the separation of the calcium in the form of the carbonate. . . . .

"All of these changes may often be very perfectly and satisfactorily traced out in a single rock-mass of small dimensions. Moreover, wherever any of the original minerals remain, they seem to be, for rocks of this class, in all cases the same. No other process of alteration could be discovered in the peridotites within the area examined; and hence it would appear quite justifiable to assume a similar origin for all such serpentine and talcose rocks as are identical with undeniable alteration products of olivine rocks, even though they may not themselves contain any remnants of their original constituents. . . . . The alteration of olivine to serpentine . . . . is . . . . too well known to need further mention. . . . . Whether the less common alteration of this mineral to hornblende . . . . also takes place in our rocks is not certain. Most of the serpentines contain considerable amphibole but no instance has yet been observed where it could not be traced with more probability to the pyroxene than to the olivine.

"In case the olivine is the only constituent which has undergone alteration, a bronzite or diallage serpentine results, in which crystals of pyroxene are porphyritically scattered through the serpentine groundmass. . . . . The alteration of the pyroxene of the olivine rocks seems to be at first always to some form of hornblende. Sections of many comparatively little altered specimens show under the microscope a tendency to develop colorless hornblende needles and fibers in the bronzite and diallage crystals . . . . This change may be continued until no vestige of the pyroxene remains. In connection with the alteration of the olivine it gives rise to hornblendic (tremolite) serpentines, which are by far the most abundant of the magnesian rocks of Baltimore County. To them belong the serpentines of the Bare Hills, some seven miles north of the city. . . . . In sections of these serpentines unmistakable traces of diallage may sometimes be discovered, although, as a rule, colorless hornblende needles and serpentine are the only silicate minerals which are present. Rocks identical in all respects with the Bare Hills serpentines have a widespread distribution

in and around the gabbro area. They are especially abundant about its edge. . . . . In many of these exposures the gradual transition to the little-altered olivine rock may be traced, both macroscopically and microscopically, with great clearness.

"Similar conditions prevail towards the western side of the area as we approach the valley of the Patapsco River. At the western edge of the bridge at Hollofields, an interesting magnesian rock occurs, in which the original constituents, olivine and pyroxene, were arranged in parallel bands. This structure is still perfectly preserved in the alternating layers of nearly black serpentine and silvery white hornblende. . . . .

"The large area of serpentine farther to the northeast, known as Soldiers' Delight, appears to be of the same nature as that at the Bare Hills. Similar rocks also occur along the southern limit of the gabbro area in the valley of the Patapsco near Ilchester.

"In many specimens of these magnesian rocks a peculiar glistening mineral is largely developed which imparts a light silvery-green lustre to a freshly fractured surface. . . . . (Microscopical and chemical tests) clearly indicate that it is talc.

"This alteration of hornblende to talc in olivine rocks was first described by Tschermak, who regarded the presence of olivine as a necessary condition of the change. . . . . Tremolite passes into talc, accompanied by a change of calcium silicate to calcium carbonate. . . .

"It seems probable that the asbestos deposits of Baltimore County . . . . may likewise be the results of the alteration of original pyroxene masses."

In addition to these areas there are several long, narrow lenses of talc and serpentine near Whitehall in the northern part of the County. Of these the only one of economic importance is that on Burns' place on the creek west of the village. Here the serpentine is hard and compact. It has been quarried to some extent, although the opening was primarily made to ascertain the quality of the rock.

CARROLL COUNTY

Tyson[58] speaks of the occurrence of chrome ores in the body of serpentine which stretches from near New Lisbon through Howard County toward the Potomac River. The area has not been further studied.

HOWARD COUNTY

The area just mentioned extends nearly through Howard County in a southwesterly direction, to within a short distance of Tridelphia. The area is about 15 miles in length and is midway between Sykesville and Woodstock.

MONTGOMERY COUNTY

Ducatel[59] in 1857, says the argillites of the Patuxent on the northeast boundary of the County pass into steatites and soapstones, followed by serpentine between Etchinson's Mills and Tridelphia. The principal mineral resources of the County occur with the serpentine.

"The tract referred to appears to be confined to the Western side of the Seneka and extends from the dividing ridge between the head waters of the Seneka and those of the Patuxent in a southern direction nearly down to the Potomac. . . . . The mineral contained within it is usually designated as the chrome ore. . . . . Wherever the serpentine rocks occur the soil is found to be poor, supporting a stinted growth of oaks and pines, and seldom adapted to any profitable cultivation. . . . That there is a great abundance of chrome iron-ore in Montgomery County there can be no doubt. . . . ."

GENERAL SUMMARY

Summarizing the foregoing, it is seen that there exists in the Piedmont Plateau a region in which the rocks are serpentine or serpentine-like, and talc. The rocks to the south of Maryland are much less serpentinized than those to the north and are generally peridotites of the dunite

[58] Tyson, Philip T. Second Rept. of Agricul. Chemist, 1862, p. 68.
[59] Ducatel, J. T. Ann. Rept. of the Geol. of Md., 1837, p. 20.

type. The area underlain by these rocks is in general bare and uncultivated, or covered with a tangled scrub owing to the sterility of the soil, which is due to the large amount of magnesia contained in it and also to the fact that the rocks decompose slowly and the products of decomposition are washed away nearly as fast as they are formed.

On Staten Island there is a body of serpentine covering an area of some $13\frac{1}{2}$ square miles. The rock here is regarded by Britton as derived from limestones and tremolite strata, and he found no proof of its being a metamorphosed igneous rock. Julien, on the contrary, regards it as derived from a hornblende schist. No olivine materials occur here and the rock lies nearly parallel to the neighboring gneisses and limestones.

In New Jersey there are several outcrops of serpentine. Merrill regards the Montville serpentine as derived by metsomatic processes from pyroxene, and since no free silica in the form of chalcedony is found, as is almost universal when the serpentine is formed from dunite, he thinks that there must have been sufficient magnesia furnished from other sources to change the whole into serpentine.

In Pennsylvania there are many serpentine exposures extending across the southeastern portion of the state, in Northampton, Montgomery, Delaware, Chester, and Lancaster counties. Peck regards the Northampton County serpentine, which he says always occurs along fault lines, as due to the alteration of hornblende and phlogopite. The tremolite with which it is associated he thinks is due to the alteration of silicates of lime and magnesia. The dolomitic beds underlain by gneisses have furnished the magnesia and silica and lime. Merrill suggests that the association of the serpentine with the tremolite rock indicates its genetic relationship, for there is a gradual transition of tremolite to a rock composed of tremolite, serpentine, and calcite.

Rogers regards the steatite of the Chestnut Hill area in Montgomery County near Philadelphia, as having been metamorphosed to its present condition by the infusion of magnesian matter from the dike of intrusive serpentine which everywhere adjoins it. This area is regarded by Miss Bascom as derived from an olivine rock and not from a dolomite or an

enstatite rock. The serpentine of the Lafayette belt in the same county is regarded by the Second Pennsylvania Survey as derived from an enstatite rock.

Charles E. Hall of the Pennsylvania Survey said of the areas in Delaware County, that they demonstrate the fact that the serpentine areas are shallow synclinal basins; that the steatite belongs to the same geological horizon as the serpentine; and that both are of the most recent formations there.

Frazer says of the Chester County soapstone strata that they are only mica slate beds with the mica wholly replaced by talc. Of the Paoli belt Rogers says that it is rather an impure talcose slate largely impregnated with serpentinous matter, than a zone of genuine intrusive serpentine. He speaks of the western end of it as being bordered both north and south by the talcose slate formation. Of the State Line serpentine he says that it comprises both true injected serpentine and serpentinous steatitic talc-slate. He dwells upon the fact that there are two kinds of serpentine here, one stratified talc-slate and the other the true igneous serpentine. Rand, in 1896, also regarded the serpentines here as of two kinds; one derived from altered igneous rocks, either pyroxenic or chrysolitic; and the other of doubtful, and perhaps varied, origin—that from Fritz Island being altered dolomite.

Rogers says of the Lancaster County serpentines, as he said of the areas in Chester County, that there are two kinds of serpentine; a stratified and unstratified one, one from dikes, and the other from impregnations by serpentinous matter.

In North Carolina the olivine rocks have suffered less alteration and the rock is chiefly dunite, but wherever the serpentine occurs it can easily be seen that it is derived from the olivine rocks. The peridotite is clearly of a later age than the gneiss, for blocks of the latter are enclosed in it.

Farther south, in Georgia, there are peridotites but no perfect serpentines, although the peridotites are in some few cases slightly altered to serpentine.

In Maryland the serpentine occurs in the counties of Cecil, Harford,

Baltimore, Carroll, Howard, and Montgomery. The rock has been quarried for building purposes in Harford and Baltimore counties but is principally as the rock containing chrome ore that the serpentine has been worked. Chrome ore has been found in all of the counties named but it has been worked chiefly in Baltimore, Harford, and Cecil counties.

Bascom regards the serpentine of Cecil County as altered peridotites and pyroxenites, the more common origin being the peridotite and says that in different localities gradations may be traced from completely altered to only partially altered peridotites and pyroxenites. The serpentine is always accompanied and is sometimes completely replaced by a final product of alteration—talc. Feldspar and flint are associated with the rock in various localities.

In Harford County occur the largest quarries from which serpentine has been taken for building and decorative purposes, those at Cambria and Broad Creek being the largest. At the Broad Creek quarry occur two kinds of serpentine, a green and a black, the latter containing more magnetic iron.

In Baltimore County there are numerous areas, the principal ones being those at the Bare Hills and Soldiers' Delight. The serpentines are here chiefly derived from the olivine rocks. By far the most abundant of the magnesian rocks of the county are hornblende serpentines derived from pyroxene-olivine rocks. Where the olivine solely has been altered bronzite or diallage serpentine results. Hornblende is frequently altered to talc in these rocks with the separation of calcium carbonate.

In Carroll, Howard, and Montgomery counties are areas of serpentine which have, however, only been examined with reference to the chrome ores.

It is thus seen that in the region of serpentines extending from New York to Georgia, which in all probability are similar, the origin has been variously explained. Rogers dwells upon the fact that there occur here two kinds—an injection and a replacement serpentine—and this is also noted by Rand. That limestone or dolomite is the original mother rock of the Fritz Island serpentine is held by Rand and a similar view is held

by Britton for a part of the Staten Island rock. Hornblendic rocks have altered to serpentine in Staten Island (Julien), and in Northampton County, Pennsylvania (Peck). Merrill regards the Montville, N. J., serpentines as derived from pyroxene. The serpentines regarded as derived from olivine rocks and which include the greater part of the rocks studied, are those of Chestnut Hill, Pa., and Cecil County, Md. (Bascom); part of the State Line serpentines (Rand); the Bare Hills and Soldiers' Delight area (Williams); and those of North Carolina (Pratt). The soapstone and serpentines are generally held to be of the same age and a geologic unit. Hall believed them to have been deposited in shallow synclinal basins; Frazer and Rogers thought that the soapstone bodies were formed by replacement or infusion of magnesian matter; Bascom and Williams that the talc is a final stage of alteration of the serpentine.

HISTORICAL

It is probable that the λιθος ὄφιτης of Dioskorides and the *Ophites* of Pliny were applied to serpentine. The name ὄφις may have been given to it on account of the spotted appearance, like that of a snake, or it may be that it was given on account of the use made of the mineral as an antidote for the bite of snakes as mentioned by Dioskorides. Later the name was translated into Latin (*Serpens*, creeping, as a serpent) as *Serpentaria* by Agricola in 1546 (*De natura fossilium*); Serpentina by Boetius de Boot; *Marmor Serpentinum* by Wallerius in 1747 (Mineralogie); *Serpentin* by Cronstedt in 1758 (Mineralogie, p. 76) Emmerling in 1793 (Mineralogie, p. 384) used it as a family name in the Talc order. Haüy in 1822 in his Mineralogy speaks of the serpentine also as a species of the genus talc.

In 1810 Leopold von Buch,[60] observing the frequent association of the serpentine with gabbro, suggested that it might be an extremely fine-grained gabbro in which it was impossible to recognize the individual minerals, or a gabbro containing a large proportion of talc.

In 1823 Haidinger,[61] opposing von Buch's views, claimed that serpen-

[60] v. Buch, L. Berlin Magazin d. naturf. Freunde, Bd. IV, pp. 142, 148.
[61] Haidinger, W. K., Gilb. Ann., 1823, Bd. LXXV, p. 385.

tine was a distinct mineral with a definite crystalline form which he described in the serpentine from Snarum, in Norway, but in 1831 Breithaupt[62] declared that Haidinger's forms belonged to olivine. He speaks of other forms which are not like olivine and he thus early supposed that serpentine takes the forms of pyroxene and amphibole as well as of olivine. Assuming this he says that the process is perhaps applicable to large serpentine masses which may, therefore, be nothing else than altered hornblende or diorite strata.

Following this there were numerous discussions on the origin of the Snarum crystals in which Scheerer, Herrmann, Tamnau, Naumann, and Blum took part, and the question was only settled in 1851 by Quenstedt and G. Rose[63] who showed that the "crystals" consisted of 30 per cent of serpentine and 70 per cent of olivine, and that the inner cores of the crystals were still composed of the latter mineral. Rose concluded that all the crystals which had been called serpentine were simply pseudomorphs after olivine, hornblende, augite, diallage, chrondrodite, spinel, and mica, as had already been shown by other investigators, and that serpentine itself did not crystallize. He also said that wherever and in however large masses serpentine occurs, it is never primary but has been built up by later replacement processes. This idea was extended by many later observations. In 1854 Briethaupt[64] described a gabbro in which the augite was at times entirely altered to serpentine, as were also some of the feldspars. In other places eclogite appeared to be changed to serpentine. Hochstetter[65] in 1854 observed in the serpentine of the Granulitgebeite of Bohemia indications that it was originally a hornblende rock, although later observations of von Camerlander[66] indicate that it was derived from an olivine-augite rock. About this time G. Bischof pointed out that serpentine belongs to the last alteration product of minerals and that it seldom undergoes further change.

[62] Breithaupt, Aug., Scherigg. N. Jahrb. Chem. u. Phys., 1831, Bd. III, p. 282.

[63] Rose, G. Zeitschrift der Deutschen geologischen Gesellschaft, Bd. III, 1851, p. 108.

[64] Breithaupt, Aug. Neues Jahrn., 1854, p. 181.

[65] Hochstetter, F. von. Jahrb. geol. Reich. Anst. Wien, 1854, p. 1.

[66] von Camerlander, Carl. Zur Geologie des Granulitgebeites von Prachatitz. Jahrb. k-k. Geol. Reich., Bd. XXXVII, 1887, p. 124.

In 1860 T. Sterry Hunt[67] assigned an aqueous origin to the Canadian serpentines, chlorites and steatites and said that they were formed by reactions between the soluble silicates of calcium and alkalies from decaying rocks and the magnesian salts from natural waters. He still held this view in 1886.[68]

Up to this time there had been no rocks known composed entirely of olivine, but in the early sixties they were described from numerous localities. Sandberger said in 1866[69] that serpentine which contains pyrope, bronzite, chrome-diopside, or picotite must have originated from olivine rocks, since only in these rocks do such minerals occur as original constituents. He found the rocks near Tringenstein to be from one-quarter to one-sixth fresh olivine.

In 1867 Tschermak[70] published a paper confirming the results of Sandberger. Up to this time it was generally supposed that almost any kind of rock could be altered into serpentine, since it was found in the field that transitions could be traced from many rocks to serpentine. Tschermak showed that there might occur a considerable variation in the mineralogical composition of any rock mass, and that an olivine-bearing rock with no feldspar might pass gradually into a feldspar-rich and olivine-poor rock. If in a such mass the olivine became altered to serpentine, a transition might be traced in the field from a feldspatic rock without olivine to a serpentine, yet this does not show a serpentinization of a feldspar rock.

The work of Sandberger and Tschermak produced a reaction against the earlier views and for a time it was thought that serpentine could only be produced from olivine rocks. In 1869, however, J. Roth[71] showed by chemical equations that this view was too narrow and that all alumina-free or alumina-poor magnesian silicates might alter into

[67] Hunt, T. Sterry. Canadian Naturalist, June 1860; Amer. Jour. Sci. (2), vol. xxxii, 1861, p. 286.

[68] Hunt, T. Sterry. Mineral Physiology and Physiography, 1886, p. 501.

[69] Sandberger, F. Ueber Olivinefels und die in demselben vorkommenden Mineralien. Neues Jahrb. B., 1886, p. 392.

[70] Tschermak, Gustav. Sitz. Wein. Akad., 1867, Bd. LVI, p. 283.

[71] Roth, J. Uber den Serpentin und dis genetischen Beziehungen desselben. Abhandl. Berlin Akad., 1869, p. 329.

serpentine. According to his view, therefore, olivine, augite, diallage, hornblende, enstatite, and bronzite might form serpentine.

In 1871 Drasch,[72] by chemical and microscopical studies, divided serpentines into two classes—the true serpentine and the "serpentine-like" rocks. In both of these the chemical composition showed them to have the same composition but the microscope revealed that the former showed the typical mesh structure of rocks derived from olivine, while the latter do not possess this structure and were derived from diallage. (This mineral was later shown to be augite.)[73] This latter rock often shows a flaky structure, and in an example which the author mentions, is the serpentine from the Windisch Matrey in northern Tyrol, which is interstratified with a calcareous mica-schist. The rock is often cut by veins of calcite, asbestos, and chrysotile.

An analysis of the rock is given as follows:

SiO_2	41.57
Al_2O_3	0.67
Fe_2O_3	2.63
FeO	5.31
CaO	1.22
MgO	36.66
CO_2	0.51
Loss	11.88
	100.45

This analysis is that of a serpentine, but it differs from a true serpentine in that it is not acted upon by hydrochloric acid.

In spite of all these determinations Doelter[74] continued to maintain that it was still undetermined whether serpentine was ever derived from any other mineral than olivine, and he regarded descriptions of pseudomorphs after any other mineral as doubtful.

[72] Drasch, Richard von. Ueber Serpentine und serpentin ähnliche gestein. Tschermak's Mineralogische Mittheilungen, 1871, pp. 1–12.

[73] Hussak, Eugen. Ueber einige alpine Serpentin. Tscher. Min. Mitt., Bd. V, 1883, p. 61.

[74] Doelter, C. Ueber das Muttergestein der bömischen Pyropen. Tscher, Min. Mitt., 1873, pp. 13–18.

In 1875 Weigand[75] showed in the serpentines from the Vosges Mountains, that amphibole and bronzite might also be altered to serpentine, confirming the statement made some forty years earlier by Breithaupt, and by Hochstetter twenty years before. Of the serpentines of the Vosges those of Bonhomme and Starkenbach are plainly derived from olivine, showing under the microscope the characteristic mesh structure, but that of the Rauenthal is quite different. It occurs in a gneiss series in which there are hornblende members. By an increase in the hornblende the rocks pass into an amphibole and it is with the latter rock that the serpentine occurs. From the margin of the serpentinized areas inward there is a gradual increase in the amount of serpentine until the rock is wholly a serpentine although differing from normal olivine serpentines in often having a schistose structure. Under the microscope the mesh-structure is absent, but the characteristic cleavage lines of hornblende show that the original mineral was a hornblende.

An analysis of this rock shows:

	Rauenthal serpentine	Adjacent amphibole
SiO	37.706	46.407
Al_2O_3	0.201	6.727
Fe_2O_3	10.428	4.649
FeO	—	2.107
CaO	1.677	10.642
MgO	36.602	26.252
H_2O	13.386	3.584
	100.000	100.368

This is the composition of a serpentine with much iron oxide. Weigand concludes that the serpentine was produced from the alteration of a hornblende rock and that in the change calcium oxide was removed and the alumina of the original hornblende was united with some of the magnesia to form a chlorite which is always associated with the serpentine.

[75] Weigand, Brunu. Die Serpentine der Vogesen. Tscher. Min. Mitt., 1875, pp. 183–206.

In 1883 Hussak[76] examined the rocks of the Windisch Matrey which Drasch had described 12 years before. Near Sprechenstein are lenticular masses of serpentine, talc, and magnesite which are associated with serpentinous schists and which have the same strike as the phyllites with which they occur. The green schistose variety was found to be composed chiefly of antigorite scales, with grains of magnetite and colorless augite between them. Some chlorite and staurolite occurs with it. The massive variety was found to be a normal serpentine derived from olivine.

In 1877 Bonney[77] described the Lizard serpentines and showed that they were altered olivine rocks of the Lherzolite type. The field relations of these rocks show that they are intrusive.

In 1883 Schulze[78] showed another example of the alteration of amphibole to serpentine at Erbendorf in the Oberfalz where an olivine-grammatite rock was altered, the alumina of the grammatite passing into chlorote as in the case described by Weigand.

In 1888 Merrill[79] showed that in the Montville, N. J. and in Essex County, N. Y., serpentine was produced by the alteration of a pyroxene.

In 1889 Vecker [80] described a serpentine from the southern California which he says is derived from sandstone and that augite, hornblende, quartz, feldspar, and apatite have become altered to serpentine.

Bonney[81] in 1891 published a table showing the minerals contained in the serpentines of the Lizard District, and which is as follows:

[76] Hussak, Eugen. Ueber einige alpine Serpentine. Tscher. Min. P. Mitt. Neue folge, Bd. V, 1883, p. 61.

[77] Bonney, T. G. On the Serpentine and Associated Rocks of the Lizard District. Q. J. G. S., 1877, vol. xxxiii, pp. 884–924.

[78] Schulze, George. Die Serpentin von Erbendorf in der bayerischen Oberpfalz. Zeits. deutsch. geol. Gesell., Bd. XXXV, 1883, pp. 433–460.

[79] Merrill, George P. "On the Serpentine of Montville, N. J. Proc. U. S. Nat. Museum, 1888, pp. 105–111; ibid. 1889, pp. 595–600.

[80] Becker, George F. Quicksilver Deposits of the Pacific Slope. 8th Ann. Rept. U. S. Geol. Survey, 1889, Pt. ii, p. 970.

[81] Bonney, T. G. "Crystalline Rocks of The Lizard District." Q. J. G. S., 1891, vol. xlvii, p. 467.

Localities	Olivine	Enstatite	Augite	Hornblende	Chlorite	Iron Oxides	Spinellides	Remarks
Balk Quarry					?	*	?	Red
Cadgwith	*			*		*	*	Red
Quarry north of same		*		*		*	*	Red
Enys Head, near	*	*	?	*	?	*	*	Black
Kennack Cove		*				*	*	Black calcite or magnetite in veins
Carn Spernic	*	*	*		?	*	*	Red
" "		*				*	?	Red
Lankidden Cove		*				*	?	Greenish-purple
Coverack	*	*	*			*	*	Red
"	*	*	*			*	*	Red
"		?				*	*	Dark, much disseminated opacite affected by contact
Polkerris		?				*	*	Reddish
Perthalla					?	*	*	Greenish-purple
"		?		*	*	*		" "
"					*	*		" "
"		?		*	*	*		Same but colors more separated
"				*	*	*		Same, colors in bands
Goonhilly Downs Quarry	*	*	*	*		*	*	Streaky-reddish; a brown hornblende
Helston-Lizard Road	?	?	?	*		*	*	Darl; much white horn-blende, a little brown
Mullion Cove	*			*		*	*	Nearly black; much white hornblende
Lower Predannack Quarry	*	?		*	*	*	*	Reddish; much white hornblende
Ogo-dour Cove						*	*	Black, streaky; much chrysotile
Georges Cove	*	*		*		*	*	Striped and light greenish-gray
Gew Graze	*	?	*	*		*	*	Reddish; a little brown hornblende
The Riil	*	*	*	*	?	*		Dark, white spots; feldspar or chloritoid (?)
Lawarnick Pit	*	*		*	*	*		Rather dark
Kynanee Cove		*				*	*	Striped reddish-brown
" "						*		Red, compact
Holestrow						*		Greenish-gray, veined with steatitic minerals
Pentreath Beach						*		Calcite or magnesite veins

The minerals which occur are starred.

THE MINERAL SERPENTINE

Serpentine occurs both as a mineral and as a rock and is in composition a hydrous magnesian silicate with the formula $H_4Mg_3Si_2O9$, or $3MgO \cdot 2SiO_2 \cdot 2H_2O$. In percentages the composition is silica 44.8, magnesia 42.0, and water 12.9 for the pure mineral. Often a small part of the magnesium is replaced by iron, and nickel and chromium are often present in small amounts. The mineral is soluble in hydrochloric acid with the separation of gelatinous silica.

Megascopically, it is a compact, dirty-green to black mineral with a splintery fracture and a greasy or pearly to waxy luster. The color of the rock depends upon the amount of pure serpentine present, and upon the amount of magnetite and chromite, the pure serpentine being of an oil-green color but, with much finely divided magnetite, approaching black. Chlorite gives it a dirty-green color. By the local alteration of the magnetite to iron oxide and hydroxide, the color of the rock becomes dark-brown to blood-red.

The mineral is often megascopically of a fibrous structure, sometimes it is schistose and is often interlaced with talc or chlorite. Sometimes these threads are separable but often they are not. The hardness varies from 2.5 to 5.5, depending upon the variety. The cleavage is parallel to 010 and is sometimes distinct.

VARIETIES

MASSIVE VARIETIES

1. *Noble or precious serpentine.*—A translucent variety with a rich oil-green color; sometimes quite dark. Hardness from 2.5 to 3.0.

2. *Common serpentine.*—Subtranslucent and generally dark in color. Hardness owing to impurities sometimes as high as 4.0.

3. *Bowenite.*—(Dana, Mineralogy, 1850, p. 265). A very fine-grained and massive variety. It has a hardness of from 5.0 to 6.0 and varies in color from greenish-white to apple-green. It was named by Dana and is the mineral which Bowen (Amer. Jour. Sci., 1822, vol. V, p. 346) described as Nephrite. Smith and Brush (Amer. Jour. Sci., 1853, vol. XV, p. 212) showed by chemical analyses that it is a variety of serpentine.

4. *Retinalite.*—(Thomson, Mineraolgy, 1836, vol. I, p. 201) (ῥητινη resin + λιθος stone). A honey-yellow to light oil-green variety with a waxy or resinous luster.

5. *Schweizerite.*—(Jour. pr. Chem. 1844, vol. XXXII, p. 378). Named after the chemist Schweizer who analyzed it. A very compact, greenish-yellow or pale yellowish-green serpentine with a waxy to dull luster and

with a greasy feel, from the Findel glacier at Zermatt and from the Fee glacier in Wallis. It has a splintery or shallow conchoidal fracture. Merz (Natur. Ges. Zurich, 1861, Heft 4.) says it is simply a compact serpentine.

6. *Vochauserite.*—(Kenngott, Uebers. min. Forsch. 1856–57, p. 71). An amorphous, dark-brown or greenish-black serpentine somewhat translucent; from Monzoni in the Tyrol. Named for Johannes Vorhauser.

7. *Williamsite.*—(Shepard, Amer. Jour. Sci., vol. VI, 1848, p. 249). An apple-green serpentine from Texas, Pennsylvania. Found by Williams and named for him by Shepard.

LAMELLAR VARIETIES

8. *Antigorite.*—(Schweizer, Pog. An. vol. XLIX, 1840, p. 595). Thin, lamellar in structure, separable into translucent folia. Feels smooth but not greasy. Hardness of 2.5. First found in the Antigorio Valley in Piedmont, Italy.

9. *Warmolite.*—(Nuttall, Amer. Jour. Sci., vol. IV, 1822, p. 19). A thin foliated serpentine first found at Hoboken, N. J. So called from μαρμαίρω glistening, and λιθος stone.

10. *Thermophyllite.*—(Nordenskiold, Beskrif. Fin. Min. 1855, p. 160; Phil. Mag. vol. XVI, 1858, p. 263). From λ heat, and λ leaf; so called on account of the swelling and foliation under the blowpipe. A bluish-green lamellar serpentine.

FIBROUS VARIETIES

11. *Chrysotile.*—(Kobell, Jour. pr. Chem., vol. XXX, 1843, p. 469). Delicately fibrous; the fibers usually flexible and easily separated. Luster, silky. Color, white and yellowish to green. Name from ρυσόδ gold, and τιλαι threads. Often in seams in serpentine and always at right angles to the walls. This variety includes the silky Amianthus, and is often in marketable quantities as asbestos.

12. *Pictolite.*—(Hausmann, v. Moll's Efemerid. Berg und Huttenkunde., 1808 IV. Lfg. iii, p. 401). Named from a variety found by

Hausmann in the Taberg, Sweden, alternating with layers of gypsum and magnesia; τιχρός bitter, and λιθος stone, on account of its magnesia content. Later Hausmann applied the name to fibrous serpentine with fibers sometimes, and sometimes not, easily seperable. Fracture splintery. Color usually green and generally dark. The fibers as seen under the microscope are often radial.

13. *Baltimorite.*—(Thomson, Phil., Mag., vol. XXII, 1843, p. 191). A picrolite from Bare Hills near Baltimore.

14. *Hydrophite.*—(Svanberg, Pogg, Ann., vol. LI, 1839, p. 525). A compact to fibrous variety from Taberg, in Sweden, with a high percentage of water content. Occurs with much magnetite.

15. *Jenkinsite.*—(Shepard, Amer. Jour. Sci., vol. XIII, 1852, p. 392). Named after J. Jenkins of Monroe, N. Y. A fibrous, pale-green crust on compact magnetite found in Orange County, N. Y. Smith and Brush (Amer. Jour. Sci., vol. XVI, 1853, p. 369) gave similar analyses to this and Hydrophite.

16. *Metaxite.*—(Brithaup, Scherige N. J. Chem. Phys., vol. III, 1853, p. 276). From μέταξα raw silk. A feeble silky lustrous translucent serpentine occuring in white crystalline limestone in Saxony. Hardness from 3.5 to 4.0. Fusible before blowpipe. Under the microscope the fibers are often divergent.

MICROSCOPICAL CHARACTERISTICS

Under the microscope serpentine appears to be made up principally of fine fibers, thin prisms, or thin laminated plates. When the fibers are parallel they generally show that the axis of least ease of vibration is in the direction of the fibers, and bisects the optic axes. In flakes and laths the dispersion is $\rho > v$, therefore positive. At times in a felty aggregate the optical characters counterbalance, and the mineral may appear isotrophic. According to Tschermak, fibrous serpentine has the axis of least ease of vibration at right angles to the direction of the fibers, and the greater parallel to them, and has a large optic angle. Many varieties, however, have positive character and show interference figures in sections cut at right angles to the fibers.

The extinction is parallel to the fibers and the mineral shows a faint pleochroism, $\mathfrak{a}$ and $\mathfrak{b}$ paler green than $\mathfrak{c}$. The double refraction is weak and the interference colors are therefore low; $\gamma - a = 0.013$. The index of refraction is low, being about the same as Canada balsam, therefore the relief is low. The plane of the optic axes is parallel to the longer direction of the prismatic cleavage; thus in chrysotile c = $\mathfrak{c}$, b = $\mathfrak{a}$, a = $\mathfrak{b}$. The mineral is biaxial with a variable angle which is often large; 2 E = 16° to 98°, depending upon the percentage of iron present.

SERPENTINE PSEUDOMORPHS AFTER OTHER MINERALS

Serpentine never occurs in original crystals but always as pseudomorphs after other minerals. Among these the following have been described:

Augite	Merrill	Easton, Pa.
Apatite	Dana	Tilly Foster Mine
Biotite	Dana	" " "
Bronzite	Rosenbusch	Baste, Harz.
Brucite	Dana	Tilly Foster Mine
Calcite	Dana	" " "
Chlorite	Dana	" " "
Chondrodite	Dana	" " "
Chromite	Heddle	
Chrysolite	(See Olivine)	
Diallage	Becke	Neokhori
Diopside	Merrill	Montville, N. J.
Dolomite	Rand	Chester Co., Pa.
Enstatite	Wadsworth	Melbourne
Feldspar	Becker	California
Garnet	Blum	Schwarzenburg
Hornblende	Dana	Tilly Foster Mine
Macacolite	(See Diopside)	
Monticellite	v. Rath	Monzoni
Olivine	Rose	Snarum, Sweden
Phlogopite	Peck	Easton, Pa.
Ripidolite	Dana	Tilly Foster Mine
Spinel	Blum	Warwick, N. Y.
Staurolite	Rand	Mill Creek, Pa.
Tremolite	Merrill	Easton, Pa.
Quartz	Becker	California

THE ROCK SERPENTINE

Serpentine often forms entire rock masses and is generally quite compact and massive, although at times it is schistose and thinly laminated. The color varies from green to yellow or brownish-red, and often shows clouds and streaks on account of the magnetite or chromite occurring in it. The hardness is generally low but it varies with the other minerals contained in it. The rock is composed primarily of mineral serpentine but it generally also contains fragments of the minerals from which this was derived such as olivine, bronzite, diallage, diopside, and hornblende. Chlorite is often present in large quantities and gives the rock a dirty-green color. Magnetite and chromite are generally present and in the Ural Mountains serpentine is the mother rock of platinum. Brucite, talc, picrolite, and other hydro-silicates occur in fractures and cracks, and opal intersects it in all directions, at times increasing the hardness very materially.

Chemically the composition is about that of the mineral serpentine, but variations occur which are due to difference in its origin. The amount of water varies, as does the specific gravity and the CaO content. Cr_2O_3 is seldom lacking in the rock, although it is often present in small amounts.

The majority of the serpentines are derived from the olivine rocks and under the microscope the appearance depends upon the original rock from which it was formed. It is often possible, when the change has not gone too far, to recognize from the fragments remaining, the original minerals from which the rock was formed.

THE ALTERATION OF OLIVINE TO SERPENTINE

The thin sections under the microscope show, when the rock has been derived from olivine and the process of alteration has not gone too far, a peculiar structure which has been called the "mesh-structure." The original crystal of olivine is first altered to serpentine along the fracture lines; the iron contained in the olivine is changed to magnetite and most of it is deposited along these primary cracks. As the serpentinization progresses the increase in bulk of the mineral forces the cracks still

farther apart and so permits the more rapid serpentinization of the remainder. (*See fig. 8—1.*) According to the degree to which this is continued, the mineral shows under the microscope an irregular net work of ore particles; the irregularity of the cracks due to the fact that the olivine possesses no good cleavage. The first-formed fibers of serpentine are arranged along these cracks perpendicular to the edges. In the enclosed spaces may remain fragments of the unchanged olivine, or the entire space may be filled with serpentinized material; here, however, the structure is seldom fibrous but is rather platy. These spores, too, seldom contain ore, or if they do, it is in a very much divided

FIG. 8.—Textures of serpentine formed by the alteration of 1. olivine, 2. amphibole, and 3. pyroxene.

state. The color of this central filling, if of serpentine, is paler and between crossed Nicols, shows very much darker. It may even at times appear entirely isotropic, or at least very dimly lighted.

THE ALTERATION OF AMPHIBOLE TO SERPENTINE

Serpentine derived from amphibole shows what Weigand[82] called the "Gitteroder Fensterstructure." In this structure the characteristic 124° cleavage of the amphibole remains and along these cleavage lines the first formed fibers of serpentine stand out at right angles. In the spaces between the cleavage cracks the original mineral remains, or it is entirely replaced by entangled masses of fibrous serpentine showing dark between crossed Nicols, as in the case of olivine. The first formed

[82] Weigand, Bruno. Die Serpentine der Vogesen. Tscher. Min. Mitt., 1875, p. 198.

fibers usually polarize in brilliant yellows in a slide of the usual thickness. In the pinacoidal section the cleavage of the hornblende is right-angled, and is not in this case characteristic, for the vertical sections of bronzite show similar right angled cleavage lines; therefore only sections parallel to the 010 face or at least faces approaching this are characteristic. The net-work of ore inclusions are usually lacking in the hornblende serpentines; all the particles being usually concentrated in larger, isolated masses.

THE ALTERATION OF PYROXENE TO SERPENTINE

Since the cleavages of pyroxene are at right angles, it may be seen that the serpentine derived from these show a "Balkenstructure." In this there is a right-angled net-work in which parallel beams or bars are arranged at right angles to the long axes of single beams. (*See fig. 8—3.*) These straight fibers show pleochrosim of yellowish-green to pale blue-green. In the pyroxenite-serpentines the absence of picotite is noticeable. This beam structure was first described by von Drasch in 1871 in the serpentines of Windisch Matrey, but at that time it was not traced back to pyroxene. Hussak[83] first recognized its meaning in 1883.

THE MORE IMPORTANT ROCKS FROM WHICH SERPENTINE IS DERIVED

Olivine-rich rocks: Pyroxene rocks carrying olivine as Lherzolites, pikrites, bronzite-olivine rocks; amphibole-bearing rocks.

Olivine-bearing hornblende rocks:

Pure amphibole (actinolite, tremolite) rocks.

Olivine-bearing pyroxene (enstatite, bronzite, augite, and diallage) rocks.

The view held by T. Sterry Hunt and the older Canadian geologists that serpentine is an original sedimentary rock is no longer considered tenable.

[83] Hussak. Eugen. Ueber einige alpine Serpentine. Tscher. Min. Pet. Mitt., vol. v, 1883, p. 65.

SERPENTINIZATION

PHYSICAL CHANGES

A comparison of serpentines and the rocks from which they were derived, shows that there has been a great change megascopically as well as microscopically. The change as seen under the microscope has already been described in the preceding chapter. Megascopically there is seen to be a change from a crystalline rock to one that is aphanitic and compact. From a rock composed of several essential minerals, a rock is formed consisting of only one. The rock, originally massive, unbroken and unfractured, is now shattered, full of joints, fractures, seams, and veins. Many of these joints show slicken-sides and others may be filled with opal or calcite. Often too, crystals of magnetite are scattered throughout the rock. The original rock was subject to alteration. The serpentine is relatively stable and, although itself a soft rock, is yet able to withstand weathering much better than the original rock.

CHEMICAL CHANGES

If we compare analyses of olivine and serpentine we have apparently a simple change. Teall[84] gives the following analyses by Holland:

	Olivine from snarum	Serpentine derived from it	Theoretic composition of serpentine
SiO_2	41.32	42.72	43.48
Al_2O_3	0.28	0.06	
FeO	2.39	2.25	
CrO	0.05	tr.	
MgO	54.69	42.52	43.48
H_2O	0.20	13.39	13.04

The change is not, however, as simple as it appears. In the analyses we see a slight loss of magnesia and an increase of water. Hunt[85]

[84] Teall, J. J. H. British Petrography, 1888, p. 105.
[85] Hunt, T. Sterry. Mineral Physiology and Physiography, 1886, p. 506.

has shown that in the alteration of olivine to serpentine there must be an increase in bulk of 33 per cent owing to hydration. In the formation of the serpentine rocks we know that there has not been such an increase. It is true that the serpentine is everywhere broken up by fractures and joints and veins cut the rock in every direction, but on examining the rock under the microscope we see that the original minerals, even though entirely altered to serpentine, show no great distortion. The uniform polarization of the particles shows that there has been no very great disturbance. The particles may have become separated to a slight extent, but they have not been crushed and sheared as they would have been had the original rock increased in bulk as much as 33 per cent. The rock itself, it is true, shows many slickensides, indicating movements, yet often this appearance of a slickenside may not be due to a movement. Lemberg[86] has shown that there is often a luster in hornblende rocks not only upon the smooth surface, as there would be in slickensides, but often occurring on rough surfaces and sometimes in a rock containing feldspar and hornblende in which case the hornblende shows the gloss but the feldspar does not. This gloss he ascribes not to movement, but to an infinitesimally thin coating of a hydroscu-magnesian silicate. In some cases, therefore, there may have been no great sliding in the serpentine mass although the formation of the magnesian silicate took place in cleavage cracks due to fracture in the original minerals.

Taking the theoretical composition of serpentine—$H_4Mg_3Si_2O_9$, or $3MgO \cdot 2SiO_2 \cdot 2H_2O$, we find two molecules of water. Experiment has shown that one of these may be driven off at a temperature of 100°C., and the other only on raising the mineral to a much higher temperature.

The low alumina content of serpentine is an indication of the fact that only alumina-free or alumina-poor silicates are capable of producing serpentine; for, as J. Roth pointed out,[87] in ordinary weathering agents,

[86] Lemberg, J. Ueber die Contactbildung bei Predazzo. Zeits. deutsch. geol. Gesell., Bd. XXIV, 1872, p. 262.

[87] Roth, Justis. Ueber den Serpentin und die genetischen Beziehungen desselben. Abh. k. Akad. Wiss. Berlin, 1869, p. 329.

water, carbonic acid, and oxygen, are incapable of removing alumina. In serpentine, besides hydration there is a subtraction of MgO and FeO, and probably also of SiO_2. Now magnesium-hydroxide, as well as magnesia, is practically insoluble in pure water, but B. Müller found by experimenting with carbonated water upon powdered olivine, that a part of the SiO_2 and MgO and most of the FeO went into solution, and that the composition of the part remaining was similar to serpentine with the exception of the water content.

Since, therefore, serpentine can only be produced from a non-aluminous mineral Roth proceeded to consider the different minerals capable of producing it. These are: olivine, the orthohombic pyroxenes, diallage and non-aluminous hornblende and augite. The process of serpentinization begins by the oxidation of the iron and the taking up of H_2O from water containing free oxygen. Since there must be no increase in bulk some of the bases must be removed. Calcium, if present, as well as some of the magnesium, would easily be removed as carbonates. Taking five molecules of an iron-free olivine, Mg_2SiO_4 or $2mgO \cdot siO_2$, we have:

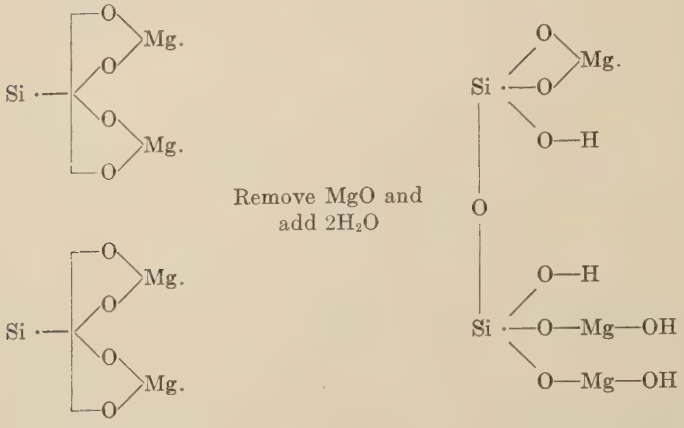
$$\begin{array}{rl} \text{Five olivine} = & 10\ MgO \cdot\ 5\ SiO_2 \qquad \text{and subtracting} \\ & 4\ MgO \cdot\ \ SiO_2 \\ \hline & 6\ MgO \cdot 4\ SiO_2 \end{array}$$

Adding 4 molecules of H_2O we have 2 molecules of serpentine; 2 ($3\ MgO \cdot 2SiO_2 \cdot 2H_2O$).

Supposing that the 4 $MgO \cdot SiO_2$ as given above is removed by carbonated water we have;

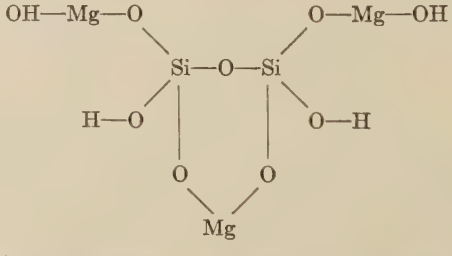
$2\ (4MgO \cdot SiO_2) + 2H_2O + 5CO_2 + 3MgO \cdot 2SiO_2 \cdot 2h_2O + 5MgCO_3$, or serpentine plus magnesite, thus explaining the frequent occurrence of carbonates with the serpentine. The calcium reaction is similar.

Brayns[88] gives a formula as follows;



OLIVINE SERPENTINE

At least two molecules of olivine are necessary to produce one of serpentine. The iron which occurs with the olivine separates out as magnetite and the magnesia forms the carbonate magnesite. Brauns prefers the unsymmetrical serpentine formula rather than Tschermak's symmetrical one:



because it explains an experiment recently performed by Clark and Schneider, who repeated an old experiment of Daubrée, whereby on heating serpentine to the melting point and driving off the water it was found to separate into enstatite and olivine.

$$3MgO \cdot 2SiO_2 = MgO \cdot SiO_2 + 2MgO \cdot SiO_2 + 2H_2O$$

SERPENTINE ENSTATITE OLIVINE

[88] Brauns, E. Betrachtungen ueber die chemische Zusammensetzung Mineralien der Serpentin-, Chlorit-, und Glimmer-gruppen. Neues Jahrb. B., I., 1894, pp. 217, 242.

In the case of the serpentinization of a non-aluminous lime-magnesia-iron pyroxene from Sala, Sweden, Roth gives the following analyses:

	I	II	III	IV	V
SiO_2	54.86	59.66	63.33	56.16	48.77
CaO	23.57	11.55	5.18	0.88	
MgO	16.49	22.28	26.31	33.96	48.88
FeO	4.44	5.44	4.36	7.74	
MnO			0.82		
Al_2O_3	0.21	0.47		1.26	2.35
	99.57	100.00	100.00	100.00	100.00

I. Fresh pyroxene (Rose). II Altered pyroxene with 8.12% water (Rose). III. Altered pyroxene with 5.52% water (Rose). IV. Altered pyroxene with 9.83% water (Svanberg). V. Serpentine with 12.33% water (Lynchnell).

In these analyses it is seen that to produce the change from the pyroxene to serpentine a large amount of SiO_2 and CaO must have been removed, or that some of the MgO has been added, both possibilities suggested by Roth.

Merrill[89] gives the following analyses of a white pyroxene from Montville, New Jersey (I) and the serpentine derived from it (II).

	I	II
SiO_2	54.215	42.38
MgO	19.82	42.14
CaO	24.71	—
Al_2O_3	0.59	0.07
Fe_2O_3	0.20	0.97
FeO	0.27	0.17
H_2O	0.14	14.20
	99.945	98.85

The formation of magnesite and calcite from the products removed from the original rock in the process of serpentinization is well authenti-

[89] Merrill, George P. Rocks, Rock-Weathering and Soils, p. 114.

cated, but that serpentine is produced from limestone and dolomites is not established. Serpentine, it is true, often occurs associated with dolomite and limestone, and since certain of them are very rich in silicates, as melacolite and tremolite, it is quite probable that the serpentine has been derived from them in the ordinary way, leaving the limestone itself unaltered. The deposition of serpentine as such without alteration in the primordial sea, as suggested by T. Sterry Hunt, is not considered to have taken place. At the present time no geologist holds that view.

Feldspar may alter to serpentine but the process is not a simple one. Bishof[90] gives the following reactions:

A silicate of lime may be decomposed by magnesium sulphate or chloridewith the for mation of magnesium silicate and calcium sulphate or chloride.

Aluminium silicate is decomposed by magnesium sulphate or chloride with the formation of magnesium silicate and aluminium sulphate or chloride (p. 69).

Calcium silicate and magnesium bicarbonate form magnesium silicate and calcium bicarbonate (v.i, p. 13).

Potassium silicate and magnesium bicarbonate form magnesium silicate and potassium carbonate (v.ii, p. 69).

C. H. Smyth, Jr.[91] gives the following formulae for the alteration of enstatite and tremolite into talc:

$$4\ Mg\ Si_2O_3 + H_2O + CO = H_2\ Mg_3\ Si_4O_{12} + Mg\ CO_3$$
ENSTATITE — TALC

$$Ca\ Mg_3\ Si_4O_{12} + H_2O + CO_2 = H_2\ Mg_3\ Si_4O_{12}\ Ca\ CO_3$$
TREMOLITE — TALC

DETAILED STUDIES OF THE SERPENTINE AREAS OF HARFORD COUNTY

The serpentines of Harford County had, up to the present time (1903), been mapped only in a preliminary way, and to the rocks had been

[90] Bischof, Gustav. Chemical and Physical Geology. English Ed., vol. ii, pp. 66, 67.

[91] Smyth, C. H. Jr. School of Mines Quarterly, vol. xvii, No. 4, 1896, p. 339.

assigned an origin similar to that of the serpentine of the rest of Maryland, that is, from the serpentinization of peridotites and pyroxenites, principally peridotites. The present work was done to fully determine the extent and areal distribution of the areas, the mode of occurrence of the serpentines, the rocks from which they were derived, and the processes of metamorphism through which they had passed to their present state of serpentinization.

The studies are based principally upon the work done by the author during the field seasons of 1901 and 1902 during which time all the areas were examined in detail, 299 specimens were collected evenly distributed over the areas, and 27 thin sections were prepared for microscopic study. Besides this material the author has had access to the specimens collected by Professor George H. Williams, the field notes of his preliminary work, and 20 slides for the microscope prepared by him.

The author's investigations and studies in the field show that there are about 25 serpentine areas in Harford County. These vary in length from a few hundred feet to 14 miles, and in width from less than a hundred feet to a mile. The areas which are fully described below, are as follows: 1. Deep Creek area, 2. Broad Creek area, 3. The Glades area, 4. Bald Hill—Scarboro—Deer Creek area, 5. Between Bald Hill and Castleton areas, 6. Castleton area, 7. Macton area, 8. Two small dikes north of Macton, 9. Soapstone knoll, 10. Mill Green area, 11. Ady area, 12. Cherry Hill area, 13. Chrome Hill area, 14. Coopstown-Jarrettsville area, 15. Cardiff area, 16. Pylesville-Clermont Mills area, 17. Federal Hill area, 18. Little Deer Creek area, 19. Carsins area, 20. Hickory area, 21. Area south of Hickory, 22. Area south of area 21, 23–24. Two areas north of Gibson, 25. Belair area, 26. Wimbledon area, 27. Fallston area, 28. Small area between 26 and 27.

The location of all these areas is shown on the accompanying map, and the numbers marked upon the map are the numbers of the specimens which are described in the following pages.

Area 1. Deep Creek.—This area is a very narrow one on Deep Creek about a mile and a quarter west of Flintville and about a half mile north

of Broad Creek. The serpentine is exposed in the creek from a couple of hundred feet north of the house on its east bank to a point opposite the house. The length of the area could not be determined for it is everywhere, except where cut by the creek, covered by the soil derived from the crinkled mica schist which borders it to the north and south. The area is probably not more than 500 or 600 feet in length.

Area 2. Broad Creek.—This is a lens-shaped area about one and three-eighths of a mile in width at the widest portion. To the north of this area is a crinkled mica schist somewhat chloritized (327 and 374).[92] To the south and separating it from Area 3 is a mica schist (331). The general direction of the area is northeast and southwest, approximately on the direction of the strike of the surrounding mica schist. From the relationship of the mica schists at the north to those at the south the mass appears to be either included in them or else intruded after the mica schists had been deposited. It is from this area that the greatest amount of material has been quarried for decorative and building purposes. On the southern border on Broad Creek, about at the middle of the area, are the Broad Creek "Verde Antique" quarries.

When visited by the author in 1901 and 1902 the quarry and saw mill appeared to have been abandoned. Most of the machinery had been removed and the buildings were in poor condition. The general nature of the "barrens" may be seen from the photograph in Plate XV taken just to the north of the quarries. Everywhere the serpentine outcrops through the soil, and the vegetation is scanty. The serpentine in this area varies from a beautiful dark-green to a rock that is nearly black. Surrounding the area on every side is a border of talcose rocks and beyond these there is a chloritic schist, grading into the mica schist and appearing as though the mica had been replaced by chlorite, the magnesium for which may have leached from the intruded magnesian rocks.

The specimens from this area are as follows:

328.—From the north boundary at the east end of the area. A dark-green chlorotic rock containing crystals of magnetite. The rock is soft, being easily scratched with the thumb nail.

[92] The numbers in parentheses throughout the following pages refer to specimen numbers.

FIG. 1. VIEW OF SERPENTINE QUARRY AND SAW-MILL AT CARDIFF, 1901.

FIG. 2. VIEW OF SERPENTINE QUARRY AT CARDIFF, 1928.

329.—South of the preceding on the road. An almost white soapstone, flaky in places. It contains a few crystals of magnetite.

330.—A compact, dark-green, typical serpentine from the same road. This was taken from a boulder at the roadside which may possibly have been brought here as road ballast. No other rock outcrops here.

332.—From the Broad Creek quarries. A compact, medium-green serpentine and typical of the area.

*333a.[93]—From the south boundary on the road to the southwest. A compact white to very light-green talcose rock with a vein of fibrous talc running through it. It contains numerous cavities from which crystals of magnetite have rusted out.

Under the microscope the rock is seen to consist of a mass of talc fibers and plates. In the vein the fibers are arranged in parallel position and extend from the two sides of the fracture, meeting in the center. The main mass of the rock is compact talc unstained by iron oxide although the vein filling was considerably stained. The ore grains and crystals are magnetite, often showing octahedral cleavage fragments.

333b.—Similar to the preceding.

*333c.—A green chlorite, nearly pure ripidolite. Under the microscope the section shows typical radiation or fan-shaped bunches of rods and plates of chlorite. Some of the plates are nearly isotropic. The fibrous plates are slightly pleochroic; pale-yellow to green. Uniaxial or nearly so. Chlorite. A very few magnetite crystals occur in the slide.

375.—From the south boundary at the western end, near lane. A chlorite schist.

*63B.[94]—From the Broad Creek quarries. A typical serpentine. Under the microscope the slide shows a typical pale polarizing serpentine. It contains an unusual amount of carbonate, possibly two-thirds of the slide.

*64B.—Same locality as preceding. A pale-green serpentine mottled with black. Not as homogeneous as the usual rock.

[93] Sections have been made from the specimens marked (*).

[94] Series B is a collection of crystalline rocks and accompanying microscopical sections from Maryland, Virginia, etc., collected by the late Professor Williams for the U. S. Geological Survey between 1887 and 1894.

Under the microscope it is like 63B but with less carbonate and with coarser fibers of serpentine. There is much ore scattered through the rock in crystals and very minute grains.

65B.—Same locality as 63B. Light-green, much slickensided serpentine.

Under the microscope it is seen to be nearly pure serpentine with very little ore. The ore that does occur is in large pieces and around these the serpentine fibers stand out at right angles in a peculiar manner.

*66B.—Chlorite rock from Deep Run, north of the boundary of Area 2. Under the microscope a typical chlorite with some magnetite. Very similar to 52B and 53B of Area 8. q. v.

The area ends about 800 or 900 feet west of the lane extending south. Adjoining the area on all sides is a chloritized schist, shown by (328), (375), and (327) farther north which is less chloritized and more schistose. Thus we have a compact serpentine body surrounded by a talc border, beyond which is a rim of chlorite schist and beyond that a crinkled mica schist.

Area 8. The Glades.—On the north boundary at the center is (334) a decomposed gneiss, and (335) a dark compact gneiss, less decomposed and consisting of quartz, mica, and feldspar. South of this is (336) a serpentine-like rock, somewhat decomposed. This continues along the road in a red clay soil where it is mingled with fragments of a mica schist. At the south boundary of the area there is a crinkled mica schist with quartz lamellae (377). This specimen was taken from the south boundary of the area about one mile east of the western end. The lens is about 2 miles in length and a half a mile wide in the widest portion. The general character of the rock is serpentinous, but throughout the area there is no compact and typical serpentine. The rock is well exposed in numerous places throughout the region but everywhere it presents the same serpentine-like characters. In the midst of the area along the creek is a quarry opening from which at some time quartz has been quarried. This association of quartz in large veins with the serpentine is not at all uncommon and occurs with most of the areas in the county. At the eastern end the serpentine-like rock extends nearly

to Broad Creek and ends on the south side of the creek. There is, however, a distinct area of gneiss extending to the north of the area and separating it from the Broad Creek serpentine. The entire area is overgrown with briers, laurel, scrub oak, and even much large timber and walking through this region is very difficult. There seems to be very little reason in the name which has been given to it—"The Glades"—for little of it has been cleared, especially in the eastern end. At the western end the location of the boundaries is not easy for the rock being very schistose when broken up by weathering and when decomposed very much resembles mica schist that is chloritized.

The specimens from the area are as follows:

1311.—Near McNabb's saw and grist mill, 1½ miles southeast of Macton. A chloritized and schistose rock. Much iron stained and full of rusty cavities. It is decomposed and looks like a serpentinized gabbro.

*69B.—At the corner near stamp's house. A massive, serpentine-like rock occurring in place in the road. A few feet from the road, near the house in a well, however, the rock is chloritized gneiss. The specimen is an actinolite-chlorite rock.

Under the microscope the rock shows its composition to be principally fibrous hornblende and chlorite. It contains magnetite and a little quartz. Professor Williams remarked of the slide that it "looks like the mother rock of many serpentines and is itself an alteration product, possibly of a pyroxene."

*71B.—In front of the next house east of the preceding. A hornblende-epidote rock. A green actinolite rock with apparent remnants of former feldspar.

Under the microscope the rock shows that it was probably formerly a gabbro. The pyroxene is now wholly changed to hornblende and the feldspar is epidote. A transition between a gabbro and a serpentine.

Area 4. Bald Hill—Scarboro—Deer Creek.—This is by far the largest area in Harford County. It extends from the Susquehanna River to a mile west of Chrome Hill, a distance of 13½ or 14 miles. The area is a continuation of what is known in Cecil County as the "State Line

Serpentine." The strip in Harford County is about a mile broad on the average, and maintains this width for the greater part of its length. At the western end, south of Chrome Hill, the area narrows down to a quarter of a mile and the direction changes from a northeast-southwesterly one to northwest. Here too the strike of the bordering gneiss and mica schist changes to the same direction and the rule that the serpentine masses follow closely the strike of the surrounding rock, is not departed from. In the eastern part of the area the rock is a compact serpentine as is also a narrow strip running along the northern boundary nearly to Deer Creek. This compact rock is shown in specimens (316), (317), (318), (319), (353), (378), (554), and (532). The western half of the area is for the most part a chloritic rock, 627 being a good example. About a mile west of Scarboro in the midst of the serpentine-like rock there is a dike of granite (75B) and (557).

All along the northern boundary the rock is a mica schist. To the south, at the east end from the river to a mile west of Dublin, the rock bounding the serpentine is a gabbro; then for a mile west it is granite; and the remainder of the distance it is a very schistose gneiss, becoming like a mica schist at the extreme western end. Toward the western end the determination of the rock to the south was often difficult on account of the great decomposition and disintegration that has taken place, in most places forming a deep covering of sandy micaceous soil.

A verbal description of the locations where the following specimens were obtained would be extremely long and confusing. To obviate this the specimen numbers have been marked upon the map, Plate XVI, at the localities where they were obtained.

The specimens are as follows:

315.—A schistose green serpentine.

316.—A medium-green, compact serpentine. Compact and contains fibrous serpentine in the cracks. There is very little magnetite and no talc.

317.—A very compact, medium, dark-green typical serpentine. The last two are from Bald Hill on the road about a half mile west of the Susquehanna River. 58B, 61B, and 62B are from the same locality.

318.—A compact, medium-green serpentine containing some magnetite.

*319.—A compact, somewhat granular, light-green serpentine of uniform color. It shows some fibrous serpentine in the cracks. There are a very few magnetite crystals.

Under the microscope the rock consists almost wholly of pale polarizing serpentine in carnation petal-like blades. In these the magnetite occurs in large crystals, few in number. There are remnants of a mineral which is slightly pleochroic, from pale-yellowish to greenish, with an extinction of about 22°. The mineral shows parallel cleavage or parallel fibers which are full of elongated, cylindrical, opaque inclusions of ore. At right angles to these fibers is shown a parting. The polarization colors are high. The mineral is diallage. In some of these diallage fragments there is a change around the borders to pleochroic hornblende, showing the beginning of the alteration of a pyroxene to amphibole. There is no indication of the presence of olivine or of there ever having been any in the rock. The appearance of the slide is an altered pyroxene.

320.—A mica schist with thin laminations of quartz and mica.

337.—A decomposed, dark-green rock. Contains ore particles and a green serpentine-like mineral.

338.—A gabbro.

*344.—A light-green, somewhat iron-stained rock which at first sight granular but is seen to be made up of fine fibers. The rock contains some magnetite. This specimen was collected from the road running south from Flintville and is about a half mile south of the flint mill on the north boundary of Area 4.

Under the microscope the rock appears to be a fibrous hornblende rock. Cf. (61B and 62B). The fibers are parallel, have a high index of refraction, a slight pleochroism, and an extinction of about 15°. At right angles to the cleavage there is a definite parting. The individuals are never terminated and are a pale green in plane polarized light. The mineral is probably actinolite. There are also remnants of a more compact amphibole, showing high blue and green interference colors,

and full of ore inclusions. In several fragments the rhombohedral cleavage of the amphibole is seen. There are a few large magnetite crystals and a little talc.

348.—A dark-green, almost black rock. Appears to be made up of serpentine and hornblende.

349.—Decomposed rock. Pale-green with rusty spots. Contains quartz and serpentine or chlorite.

350.—Serpentinized gabbro? Consists of quartz, a green mineral, and probably feldspar.

351.—Compact and somewhat schistose rock. Contains quartz, a green mineral, ore, and perhaps feldspar. Gabbro?

352.—Similar to last. The decomposed rim shows what appears to be decomposed feldspar.

353.—Serpentine or a siliceous talc. Quite hard and consisting of a pale-green fibrous mineral. Some magnetite.

354.—A fibrous vein in a compact serpentinized rock.

378.—Compact, medium-green serpentine. Somewhat inseparable blades. This is from near the fork in the road a mile and a half north of Dublin.

379.—Similar to the last but full of ore particles which make the specimen look darker than it really is. There are many pits where the ore is weathered out.

*380.—A dark-blue rock, quite soft, showing pearly white where crushed by the hammer. The rock is made up of fibers and crystals of what appears to be pyroxene.

Under the microscope the slide shows that the rock is almost entirely made up of talc, retaining the form of fibrous hornblende. There are fragments of a mineral which is slightly pleochroic and shows the rhomboidal cleavage of amphibole. One fragment of a mineral with slight pleochroism, medium-double refraction, extinction 15° to 16°, fibrous and showing partings across the fibers. It contains numerous inclusions of ore. The color is slightly greenish and the fibers are unterminated. Actinolite. There are a few patches of a gray polarizing serpentine and there is considerable magnetite. The rock has every

appearance of having been changed to talc from an actinolite-hornblende rock. It was probably originally pyroxene and the whole appearance of the slide indicates this. The rock in general appearance resembles slide 344 except that this one is altered farther and is now almost wholly talc.

381.—Decomposed yellowish-brown serpentine. Contains ore particles, many of them rusted out.

382.—Pale-green rock consisting of a fibrous hornblende probably. Somewhat decomposed and has a hardness of about 3.

383.—Dark-green to black rock consisting of quartz, feldspar, and a green mineral. Surface pitted like a weathered gabbro. This is a gabbro south of the area from northeast of Dublin.

384.—A soft, rusty, chloritic rock from a half mile north of Dublin.

*385.—Megascopically a compact, dark-green serpentine showing slickensides in the cracks. Very slightly schistose. Contains a few crystals of magnetite.

Under the microscope almost pure serpentine fibers with very little magnetite and some carbonate. The serpentine fibers are very fine.

386.—A mile and a half northwest of Dublin and north of Area 4. A chlorite schist consisting of layers of quartz and chlorite.

531.—On the north boundary of the serpentine along Deer Creek, 240 feet south of the second bridge. A compact, medium-green, typical serpentine.

546.—Gneiss. North of Scarboro.

547.—Rusty decomposed fibrous rock. Probably a serpentine or a talc rock. This specimen was taken 50 feet north of the school at the triangle in the roads north of Scarboro.

*548.—Three-fourths of a mile west of Scarboro on the road west and just west of the second lane leading north. The rock is in place all along here. It is a light-green, compact serpentine. Part of the rock seems to be in flakes or scales.

Under the microscope almost pure serpentine. The slide is pale-green in planepolarized light and shows but very little ore. Polarizes in blues and yellows. There is a very little talc.

553.—A chlorite schist. Between this area and the Ady area.

554.—A light-green serpentine from the north boundary of the area, one-fourth of a mile south of Ady. Hardness about 3. Another specimen from the same locality is very much decomposed.

555.—A very soft, rusty talc rock. Contains cavities from which magnetite has rusted out. The rock is finely fibrous.

556.—A very dark-green chloritic rock. Possibly an altered gneiss.

559.—Pegmatite.

611.—Schistose, thinly laminated rock with quartz and rusty chlorite.

612.—Similar to last with ore rusted out.

613.—Indistinctly laminated. Mica, a green mineral, and quartz; probably also feldspar. Somewhat decomposed. Gneiss?

614.—Laminated, pale-green to white talc rock. Silvery white.

616.—Gneiss. Thin bedded, mica-quartz-feldspar rock.

617.—Green pyroxene, rusty quartz, feldspar, and probably mica.

621.—Rusty-green, rather coarse-grained rock, with light spots of decomposed feldspar. Some magnetite and serpentine. Probably a gabbro with serpentined hornblende.

622.—Three hundred and eighty feet south of the second-class road leading west, south of Aad. A soft, pearly-white talc rock. Many rusty cavities.

627.—Chloritic schist with ore particles.

629.—Dirty, dark-green rock similar to 627 but not so schistose.

630.—Paler than 629, but probably the same rock.

631.—Dark-green, somewhat schistose chloritic rock, quite hard. Contains many rusty cavities.

632.—Similar to last but shows feldspar in elongated lenses.

633.—Similar but more feldspar. Gabbro?

634.—Similar with finer feldspar.

635.—Similar but less even than 634 of feldspar.

636.—Similar, schistose; parallel pyroxenes and elongated quartzes.

650.—Gneiss? Between Chrome Hill and Sharon, north of the serpentine of Area 4.

651.—Chloritic schist. Rusty cavities and a dark-green mineral. The rock is quite soft.

FIG. 1. VIEW OF SERPENTINE BARRENS AT BROAD CREEK.

FIG. 2. VIEW OF SERPENTINE BARRENS AT SOLDIERS DELIGHT.

652.—Gabbro? Quartz, green pyroxene and feldspar.

653.—Thin laminated chloritic schist.

654.—Rusty laminated chloritic schist.

667.—Schistose chloritic rock with layers of quartz or feldspar. Shining green.

668.—Dark-green chlorite schist with magnetite crystals.

814.—Crinkled mica schist, nearly "bran" gneiss.

*815.—A mile southwest of Chrome Hill at the western end of Area 4. A light-green serpentine. Much slickensided. Shows much iron ore on slickensides which is a yellowish-green. Very much large magnetite.

Under the microscope. Almost pure serpentine fibers. A pure serpentine is unusual at this end of the area. It is possible that this is separated from the main area for there is a strip of micaceous sandy soil 400 feet wide separating this from the main boundary. Under the microscope there are some remnants of a mineral which appear dark-brown and remain so when polarized. Non-pleochroic. The magnetite in the slide is in large crystals.

834.—Laminated, wavy chloritic schist with rusty cavities.

835.—Laminated chlorite schist with magnetite.

836.—Crinkled talc schist. Rusty and silvery-white. Harder than talc schist usually is.

*45B.—Compact serpentine. One and a quarter miles west of Chrome Hill and one-third of a mile south of the contact.

Under the microscope the slide is seen to consist of pure serpentine fibers with grains of magnetite and dolomite and some talc.

*58B.—Serpentine from the Dublin Pike 2 miles northeast of Dublin. Under the microscope the slide consists of typical serpentine in rather coarse blades and fibers. Some of the serpentine appears nearly isotropic. There are patches of compact ore but no fine dust.

*61B.—From Bald Hill, east end of the area. Fibrous hornblende rock. Under the microscope rock composed entirely of interlacing individuals of finely fibrous green hornblende. Appears as though it were pyralite after pyroxenite. Very little chlorite. Cf. 74B.

*62B.—Locality same as last. Fibrous hornblende rock. Under the microscope like the preceding but more serpentinized especially in the *centers* of the hornblende crystals. The hornblende looks still more as if it were secondary after pyroxene.

*72B.—North edge of the area on the road from Macton to the Dublin Pike. Granular serpentine. Under the microscope. A felty mass of talc and fibrous serpentine.

*74B.—Fibrous hornblende rock from one mile southwest of Scarboro in the creek west of the cross road. Under the microscope exactly like 61B but fresher and coarser. Contains a few magnetite crystals.

75B.—A granite dike.

76B.—Locality same as 74B and 75B. Hornblende-epidote rock. Cf. 71B of Area 3. Exactly like specimen 71 but fresher. Dr. Williams said of this specimen that "it shows still more distinctly its gabbro origin." The epidote in the rock is probably derived from the feldspar.

309A.—From Bald Hill, northwest of Castleton. Same locality as 61B and 62B. Almost entirely composed of a felt-like mass of talc. There is some serpentine and remnants of a biaxial mineral with inclined extinction of 20° to 25° and having a cleavage at right angles to the fibers. Probably a pyroxene.

Area 5.—This is a small area to the south of Area 4 and is between this area and Area 6. It does not show on the roads to the east or the west and is probably not over a half mile in length. The width is not over a couple of hundred feet, but the boundaries are very indistinct.

Area 6. Castleton.—This area also has indistinct boundaries. The area is on the road leading north from Castleton to Flintville and extends westerly a distance of a mile and a quarter. In its widest portion it is about 600 feet broad. Specimens from the area are as follows:

342.—From the south edge of the area, in front of the house. A soapstone, greenish and with rusty cavities. The pits are due to the rusting out of magnetite crystals. Luster pearly.

343.—North edge of area. Between this and Area 4 is a micaceous soil. The specimen is a compact green chlorite rock with rusty cavities. The rock is flaky.

Area 7. Macton.—This area extends in a northeasterly-southwesterly direction through the village of Macton. It is about a mile in length and 500 feet in width. From the creek east of Macton to the store there are many serpentine boulders in the road and it is in place at the village (389). Five hundred and fifty feet north the phyllite (390) is in place. Most of the rock here found is a chloritic serpentine rock, and there is a great deal of soapstone. Just south of the store, however, the rock is quite compact serpentine and is dark-green. To the northeast the rock is easily traced back of the houses and up the hill to its ending under the chloritic gneiss. South of this, across the creek, is a chloritic gneiss of which (56B) is a specimen and slide. At the western end the rock is more difficult to trace. It is well covered by soil and is, in part, pasture land. It may be that there is a connection between this area and the soapstone knoll to the southeast (Area 9) but no rocks are exposed and it was impossible to trace the connection. The specimens are:

389.—A compact, medium-green serpentine with chlorite.

390.—Crinkled, somewhat compact, chloritized gneiss or phyllite.

1310.—A half mile east of Macton. Very compact, dark siliceous rock with some lighter spots, and containing crystals of a brown mineral which under the microscope shows rhombohedral cleavage of about 67° and shows that the brown color is apparently due to iron stain. Extinction about 40°. Cleavage good. The mineral looks like calcite but it is insoluble in boiling HCl. The interference figure is nearly uniaxial but the double refraction is not as high as calcite and no rings show.

*55B.—Chlorite epidote rock. Broad Creek below Pyle's house. Under the microscope typical chlorite epidote aggregate. Contains some carbonate and large white areas of quartz.

*56B.—South of the creek beyond the saw-mill. A chlorite gneiss. Fine-grained chlorite and mica gneiss finely banded. Small eyes of feldspar and quartz and flakes of mica and small crystals of pyrite. Under the microscope. Irregular grains and gneissic structure of chlorite, biotite, quartz, and feldspar.

Area 8.—Two small veins a half mile north of Macton at the fork in the road near W. S. Pyle's house. The strike of these two veins is more

nearly east and west than any of the other rocks, and here appears an exception to the general rule that the serpentine follows closely the strike of the neighboring rocks. The rock here is soapstone and between this and Area 7 at Macton is a puckered chloritic slate. The two veins are distinct with the chloritic rock between and although the contact was not seen there is no doubt but that the two veins are entirely distinct. They can be traced but a short distance beyond the roads forming the fork. On either side the land is pasture land and deeply covered with soil so that no outcrops were visible. The rock was not seen in the stream to the east and it is possible that the dikes do not extend that far.

*52B.—Chloritic rock with octahedral magnetite at W. S. Pyle's house. Under the microscope shows typical, pleochroic chlorite in radiating tufts and aggregates. Contains magnetite. Isotropic, nearly colorless mineral with high refractive index. Possibly garnet.

*53B.—Chlorite rock, locally same as last. Under the microscope it is a typical chlorite in radiating groups. A highly polarizing mineral in large areas which Doctor Williams called muscovite. It seems more probable to me that it is talc, although no chemical tests were made.

Area 9. Soapstone Knoll.—A mile southwest of Macton and south of the road on the hilltop soapstone outcrops in great quantity. The boundaries were indeterminable on account of the covering of pasture land. The area may be a continuation of the Macton area but between the two there are no outcrops and it is impossible to say whether the two areas should be connected or not. The rock is a typical soft soapstone of a silvery-white color and somewhat stained by iron oxide.

Area 10. Mill Green.—This is a very narrow area extending for a mile and a quarter in a northeast-southwest direction and passing just to the south of Mill Green. At Mill Green the rock is a compact gneiss (439), consisting of quartz, biotite, and feldspar. The rock is banded in large masses and is very compact. To the east there is also a compact mica gneiss (540) which was taken 100 feet east of the road north from the Dublin road.

437.—A soft pearly-white soapstone. Slightly yellowish from iron oxide.

438.—A compact green serpentine. Contains magnetite in crystals.

534.—A brittle, schistose, fine-grained mica gneiss on one side of the specimen. The other side is chlorite. This specimen was taken from the contact between the serpentine and the gneiss at one of the few places in the county where the contact is visible. This specimen was taken 520 feet south of the T road one half mile southwest of Mill Green.

Area 11. Ady.—This is an area $2\frac{3}{4}$ miles in length and less than 500 feet in width at the widest portion. It extends from a point three-quarters of a mile southwest of Ady, through Ady and 2 miles to the northeast. To the north of this area the rock is mica gneiss (540). South of the east end it is phyllite (545). The rock of the east end of the area is chlorite schist and soapstone (541 to 544). At the center of the area the serpentine begins 130 feet east of the triangle in the road and continues as far as where the main road leads to Mill Green. Here there is little rock on the road besides the quartz. Just to the southeast of the small triangle is a vein of pyroxenite (550). From here the road as far as Ady is in serpentine only. At Ady it extends 210 feet south of the post office and then crosses the gneiss (553) which continues to Area 4.

The specimens from this area are:

541.—A compact white pearly soapstone with rusty cavities. Contains octahedral crystals of magnetite. The specimen is from the east end of the area.

542.—Same locality as preceding. The rock is the same as 541 and contains a vein of chlorite at the side.

543.—Same locality. Pearly-greenish soapstone unstained by iron oxide.

544.—Same locality. Pearly, greenish-white soapstone.

545.—Decomposed phyllite or gneiss. Quite compact. From the eastern end of the area.

550.—Pyroxenite from the southeast end of the small triangle in the roads at the center of the area.

a. Near schoolhouse. Altered pyroxenite, now green chlorite.

b. Same locality as last. Rusty, fine granular talc rock.

Area 12. Cherry Hill.—This area is about 2 miles long and three-quarters of a mile in width. The area is an oval whose northern limit passes through Cherry Hill. From here it extends a mile and a half east and three-quarters of a mile west. Along the road southwest from Cherry Hill are specimens (500, 501, 502). Beginning three-quarters of a mile southeast of Cherry Hill is (500) which is 310 feet before the first house. Between the two houses there is nothing but quartz in the road and the first rock in place is 200 feet beyond where (510) is in place. This continues along the road and is a chlorite-actinolite rock. Two hundred feet beyond the lane to the left is a 10-foot dike of (502) a quartz-gabbro. The serpentine is in place on either side of it. Five hundred feet southwest of the first building of Cherry Hill—the church—is a 200-foot stretch of road where there is nothing but quartz on the road. Then the serpentine comes in in place and in the woods back of the church to the creek and to Cherry Hill the only rock exposed is soapstone. North of Cherry Hill it extends only 140 feet where a yellow quartz sand comes in containing some mica. A mile and a quarter east, on the road, is (518) a rock consisting of a serpentinized mica schist containing crystals of quartz. Specimens (519 and 520) here also. There is much soapstone along the road (521, 522, and 523). Here also occurs an exceedingly great amount of opal in veins (524 to 529). There are many very large pieces of an opaque white opal showing a ropy exterior and stained with iron oxide. Some of the opal shows a greenish color and is not as opaque as the whiter kinds (524). The serpentine ends about 500 feet west of the house south of the lane. Up the creek to the east, about 600 feet north of the house in a gulch from the west, there is much serpentine (581) and to the west of this are numerous boulders of the same. Somewhere in this neighborhood chrome ore has been found in great quantity, but the possessor of the secret of its location died insane without revealing it. On the right of the creek is (582) a mica schist, in place, outcropping through the soil in immense exposures. Going north from Deer Creek to Cherry Hill there is mica schist on the road as far as 100 to 200 feet north of the house, then a rusty chloritic schist (589) to Cherry Hill. From this area the specimens are:

*501.—A light-green chloritic rock somewhat schistose. Very soft and easily crushed by the hammer. There are some dark stains between the layers.

Under the microscope the rock is seen to be made up of chlorite and actinolite. Cf. 69B. There is much magnetite in crystals, in beautiful cubes and octahedrons. There is a little quartz. The chlorite is green and pleochroic in slightly pleochroic blades with cross gashes. Extinction inclined.

502.—A 10-foot dike of quartz gabbro.

518.—Chlorite schist with quartz crystals and some serpentine.

519.—Chlorite-actinolite schist.

520.—Dark-green ripidolite.

521.—Pearly-white soapstone with fresh octahedral magnetite crystals.

522.—Skeleton quartz with limonite.

523.—Very rusty soapstone.

*524.—Serpentine with quarter-inch meshes of opal. Some rusty cavities. Under the microscope. An opalized serpentine. The opal has filled out the crystal forms of the original mineral in a similar way to the replacement by pure serpentine. The irregular fractures of some original mineral have been filled by opal and serpentine and a small amount of magnetite. From the appearance of the mineral in thin section it suggests olivine. There is in another part of the section a serpentinized mineral whose cleavage and general appearance suggests original bronzite. Talc occurs in a few places.

525.—Greenish veins of opal.

526.—Opaque white opal.

527.—Principally opal.

528.—Opal.

529.—Opal.

530.—A silvery-white mica rock like that of Deer Creek.

531.—Decomposed rock, serpentine or fibrous hornblende, full of rusty cavities. Contains much talc.

582.—Mica schist.

589.—Rusty chloritic schist.

Area 13. Chrome Hill.—This is a narrow area several hundred feet wide and extending about a mile and a half west of Chrome Hill. The general direction of this area is east and west, with rather a northwesterly direction. It differs in the direction of its strike from most of the serpentine areas but it still obeys the general rule of following the strike of the neighboring rocks. It is at this point that the general direction of the gneisses and mica schist changes from a northeasterly-southwesterly direction to a northwesterly-southeasterly one. It is possible that this area should be divided at the center forming two small areas. The rock here is very much decomposed and broken up and good exposures are rare. The serpentine-like rock was found both east and west of the center of the area but just east of Chrome Hill the rock was a crinkled mica schist. There are no exposures to the north of the road in the fields and the rock may not bend around as shown on the map.

Half a mile west of Chrome Hill on the northwest fork of the road the serpentine extends at least 540 feet along the road from the fork where it begins. It continues on the road east to Chrome Hill where it extends perhaps 60 or 70 feet north of the store at the corner. North of that is a mica schist (836) in place. Just east of the store is (641) a mica schist in place, and a quarter of a mile farther is (642) at the house, also a mica schist containing a few small garnets. Four hundred feet farther east, however, there is a schistose, compact, light-green serpentine (643). Just before the north and south road, three-quarters of a mill each of Chrome Hill occur (644, 645, and 646) actinolite talc schist, and here also was found the soapstone (647). The soapstone continues from 300 feet before the road half-way up to the house to the northeast. Then a sandy soil with large quartz boulders. The specimens are:

641.—Crinkled mica schist.

642.—Similar with a very few small garnets.

643.—Schistose, light-green serpentine, compact and hard.

644.—Actinolite schist.

645.—Same with some talc.

646.—Similar to last.

647.—White soapstone full of rusty cavities.

*46B.—An olivine-bronzite rock. Fresh. West of Chrome Hill. Under the microscope the rock shows olivine and bronzite fragments remaining. Magnetite occurs in large grains and along the fracture and cleavage cracks.

*47B.—A serpentinized bronzite rock from Chrome Hill. Under the microscope the slide shows remnants of much bronzite, now partially serpentinized. There is much magnetite in large grains and crystals.

Area 14. Coopstown-Jarrettsville.—This is an oval area located about a mile east of Jarrettsville on the road to Coopstown and is about a mile and a quarter long and three-quarters of a mile in width. It is from this area that the chrome ore, which formerly formed one of the chief industries of Harford County, was obtained. At the present time the workings are abandoned and have been for many years. The pits are full of water, the buildings are nearly in ruins, and the region is everywhere overgrown with timber and is typical of serpentine barrens.

On the road on the south side of the western boundary, half way between the long north lane and the first house to the south side of the road west of it, the serpentine is in place for about 100 feet, then to within a hundred feet of the road the road is sandy and micaceous. Here, however, the serpentine is in place. On the lane to the south the serpentine extends as far as the creek, on the other side of which the rock is mica schist. There are fragments of limonite (808) on the lane north. Soapstone (809) continues on the road for 200 feet east and here (810 and 811) were also taken. Just south of the house is serpentine (813) with crystals of pyroxene (?). On the lane northeast the serpentine continues across the creek and is in place on the west bank but on the east bank there is only fine sand and gray gneiss. No serpentine crosses the road leading south to Coopstown, the material in the road being a sandy mica schist (814). Extending west from the 551-foot bench mark the rock is sandy gneiss and this continues beyond the creek to the second house where the serpentine (821) begins. A half mile west and south beyond the creek at the house the rock is a

dark serpentine (912). West of this on the creek there is no serpentine nor is there any to the south of the house although it occurs just at the house and north of it. There are no exposures in place to the east of the house but many boulders of serpentine occur halfway to the next house north of the creek at which point there are gneiss boulders in the creek which continue to the east. North of this house one-third of the distance to the road the rock is mica gneiss, the remainder of the distance to the road is serpentine. The specimens from this area are:

808.—Limonite with skeleton quartz crystals.

809.—Pearly-white soapstone with many rusty cavities.

810.—Similar to the last but with few cavities.

811.—Like 809.

*813.—A dirty-green pyroxene rock. Apparently somewhat altered to fibrous serpentine. The rock is somewhat iron-stained. Under the microscope the rock shows that it is almost entirely altered to serpentine. There are many fine inclusions of ore particles but no large crystals. The arrangement of the ore particles is in parallel lines which are in two series for each fragment, one series being at right angles to the other in some cases, but in the majority of cases is inclined. In the center of the fragments there remains a greenish-brown, slightly pleochroic remnant of the original mineral. The slide resembles 74B, a fibrous hornblende, except that in this specimen the rock is almost entirely altered to serpentine yet all the mineral fragments composing it retain their original cleavage lines, making up the entire rock. The rock was undoubtedly a hornblendite which in turn was derived from a pyroxenite.

821.—A pale-green serpentine with rusty cavities.

912.—Dark serpentine with iron-stained cavities.

1285.—A micaceous rock with veins of opal. Serpentine dark-green, somewhat fibrous and in parallel fibers. Under the microscope. Almost entirely altered to serpentine. There appear to have been two minerals in the original rock. The ore particles are arranged in some cases around subcircular centers, as formed by irregular cleavage cracks or breaks. This has the appearance of altered olivine although little

of the original mineral remains. In some cases the centers of the areas are filled by iron-stained areas. In the majority of cases, however, the cleavage lines are regular and are rhomboidal, as would be the case of serpentine derived from an amphibole. The rock may have been an olivine-hornblende rock.

*1286.—Ripidolite rock. Under the microscope the rock consists of very pale-green plates. The mineral has a very good basal cleavage. It is slightly pleochroic, has parallel extinction, and polarizes with the usual dark-green color of chlorite. There are some irregular patches of ore but none fills cleavage cracks. There is very little serpentine.

*1287.—Purple and green fibers with much opaque white mineral filling in between. Under the microscope the slide shows bands of serpentine and a mineral which polarizes in a peculiar bright-blue, probably zoisite. The white layers are magnesite, soluble in hot HCl.

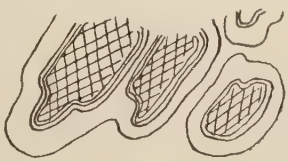


FIG. 9.—Showing central cleavage lines of serpentine surrounded by magnesite

Under the microscope they show a peculiar arrangement as shown in the figure. The central part of the areas is full of cleavage lines at 70° or 80°. Surrounding these central areas are layers of the magnesite with no cleavage, appearing as though they had been deposited around the former.

*1288.—Chromite ore. Chromite grains with a light-colored to purple and green mineral between the grains. Under the microscope the chromite grains form about three-fourths of the bulk of the slide. The section is so thick that the mineral does not show brown even on thin edges. Chemical tests show the composition to be chromite, however. The groundmass is fibrous and is almost entirely altered to serpentine. Extinction parallel.

*1289.—Fibrous serpentine, light-green and translucent. Under the microscope the greater part of the section shows complete alteration to

a pale polarizing serpentine. There are fragments of a fibrous mineral which gives a biaxial interference and which polarizes a high yellow. It may have been fibrous hornblende.

Area 15. Cardiff-Cambria.—This area is about 2 miles in length and not over 500 feet in width. It extends in a southwesterly direction from Cardiff, ending just over the state line in Pennsylvania. The termination of the northeastern end is quite abrupt and the area does not thin down gradually as it does at the southwest end and as most of the other areas do. It is possibly that a fault has cut off the northern extension but there is nothing to prove its existence. Wells drilled on the extinction to the north do not strike serpentine but go through a chloritic schist.

The serpentine has been quarried just north of the railroad station for road ballast (397). At this point the rock to the south is mica slate as is also the rock to the northwest. Northwest of Cambria Station, just north of the first lane to the left, the serpentine (441) begins and it continues on the road north at least to within 210 feet before the fork in the road. At the west of the schoolhouse near the creek are the quarries where the specimens (442 to 450) were taken. These quarries are those mentioned in the preceding pages and Plate XIV. The saw-mill and quarries were apparently abandoned when visited by the author although some of the rock has since been sent from there for exhibition at the Pan-American and Charlestown expositions.

The western end of the area probably does not reach the road a mile west of Cambria although there were a few fragments lying along the road in a direct extension of the strip. The specimens are:

*397.—A very dark-green serpentine containing much transparent light-green serpentine. Specimen shows slickensides and some magnetite. The light and dark serpentine is mixed through the specimen. Under the microscope. Almost pure serpentine with a few carbonate patches. The ore occurs in dust-like particles in irregular areas. The serpentine polarizes in neutral blues and yellows in typical carnation-leaf sheaves.

399.—Phyllite.

*424.—Compact serpentine-talc rock. Under the microscope the rock is seen to consist of a mass of felty talc with a few stringers of zoisite and disseminated magnetite crystals. There is some carbonate and some serpentine.

*443.—A very compact, dark-blue serpentine. Somewhat reddish in spots due to iron stains. Under the microscope. The section is almost colorless and shows very much ore in irregular grains. The ore is entirely opaque although a few fragments show rusty edges. With crossed Nicols the entire section is almost opaque. Almost isotropic. With very high power there are a few small spots that look like zoisite appearing usually along the ore bands. It seems to be in fibers at right angles to the ore and where it seems to fill cracks it stands at right angles to the walls. The rock is almost entirely altered to opal.

444.—Very compact, dark-blue serpentine like the last and from same locality.

*445.—Light- and dark-green serpentine. Very schistose. Contains much talc almost white. Under the microscope. The section is almost entirely talc. There is a little carbonate. The ore which occurs is in crystals, grains, and as filling in cracks. These cracks are usually irregular as the fracture cracks of olivine might be. The rock may have been an olivine rock originally but there is only the disposition of the ore particles to serve as a possible guide.

*446.—A dark-blue serpentine like 443 but has a slaty look. Under the microscope the rock is very similar to 443. With crossed Nicols it is almost entirely dark. The ore particles which occur are scattered through the rock. There are many little grains with a very high index of refraction that are probably epidote.

447.—A fibrous serpentine.

448.—The same as the preceding.

Area 16. Pylesville-Clermont Mills.—This area is nearly 5 miles long but is only about 300 feet in width. It extends from a point 1 mile northwest of Pylesville in a southwesterly direction, nearly in a straight line. At a distance of 3 miles there is probably a break in the continuity.

Beginning at the east end 1 mile northwest of Pylesville on the road

the serpentine is in place between the two houses as shown on the map (593). There is none north or south of this small outcrop. Through the field to the west the rock continues. East of the road some years ago there were a number of pits but they have now long since been filled up and hardly any trace of them remains. The pit farthest to the east was between the forks of the creek. There is no trace of serpentine or soapstone at this point. At the west of the road in the cellar of the house serpentine was cut through in excavation. Two miles west of Pylesville at the lanes north and south occurs a schistose, light-green talc (461). The limit to the north is at the house to the north of the road and the band is here about 210 feet wide. It does not extend to the south of the road. A mile farther southwest there is a compact, soapstone-like rock (677 and 678) in place just at the house. The strip is very narrow. A mile farther to the west (1 mile north of Clermont Mills) is a compact, light-green, typical serpentine. The specimen (476) is from the south side of the strip. This is 440 feet south of the house farthest to the south of the pair of houses. Two hundred and eighty feet south of the long lane there is a schistose-like rock (477) in place, and this is the last place here where the serpentine shows in the road although 600 feet farther south there is a decomposed rock (478) in the clay banks, but only in a very small place. One mile farther west where the creek crosses the road there is a strip of serpentine (472, 473) perhaps 50 or 75 feet in width just west of the creek. One half mile farther east and $2\frac{1}{2}$ miles south of Harkins, there are many serpentine boulders (604) but none shows in place. The boulders are up to 3 and 5 feet in diameter and are about 100 to 125 feet south of the fork. North of this area there is mica schist which extends to the creek. From this area the specimens are:

414.—Greenish mica schist.

461.—Schistose, light-green talc rock.

472.—Pale-green and silvery talc schist; some actinolite?

473.—Dark-green, slickensided, very soft serpentine or talc.

476.—Typical, compact, light-green serpentine. Not schistose.

477.—Schistose serpentine-like rock.

478.—Pale-green schistose serpentine rock.

481.—Silvery soapstone with rusty cavities.

604.—Hornblende (?) crystals in a pink feldspar.

676.—Mica schist. Locality south of the following specimen.

*677.—Medium-green serpentine or talc with layers of white talc. Rock quite soft. Many rusty cavities. The white part softer than the green. Numerous talc veins running through it. Under the microscope between crossed Nicols the slide is almost opaque. The lighter particles show much like talc. The whole rock is probably a mass of interlaced talc scales. The slide is quite thick. There are numerous beautiful magnetite octahedrons.

678.—Same as last.

Area 17. Federal Hill.—This area extends southwest from Clermont Mills for a distance of about 4 miles. At the fork in the road beyond Branch Creek soapstone occurs in the road. On either side is mica schist. Northwest of Federal Hill about a mile at the lane the serpentine begins. It is about 400 feet wide in all and extends just around the bend in the road. At the house up the lane the serpentine occurs and extends to the north only and then on across the creek to the northeast. One mile farther southwest at the lane the rock is phyllite (743) and this continues up the lane as far as the bend. At this point to the sides of the lane through the fields the only rock seen is soapstone. Beyond this again mica schist. One half mile farther to the west, about 600 feet north of the bend, is serpentine and this continues for about 300 feet. On the lane west of this just at the house is a ledge of (747), a mica schist. One hundred feet farther up is (748), a schistose green hornblende rock. This only a very short distance—then mica schist on up to Deer Creek. The specimens are:

746.—A magnetite chlorite schist.

747.—Chloritic mica gneiss.

748.—A schistose, green, quartz hornblende rock.

Area 18. Little Deer Creek.—This is a narrow area about 2 miles long running parallel with the western end of area 17. The eastern end of the area is a green schist (738) and comes in at 150 feet east of the creek

a quarter of a mile before the school. At the creek the strike is N. 60° E. and the dip 75° N. This rock continues nearly to the schoolhouse along the road and extends back of the schoolhouse to the creek. Beyond the school and around the bend in the road the rock is micaceous (739) and this continues around the bend and down to the southwest road, which is 310 feet before the mill is reached. Here a peridotite or gabbro (740). This continues to the creek. In front of the house is a ripidolite rock and also soapstone (741). Two hundred feet east of the creek the phyllite comes in (742). At the creek, however, the rock is soapstone (744) and 450 feet southwest serpentine (745) with pyrite. From here southwest for 460 feet the rock is all serpentine except a distance of about 100 feet in the center where no rock is exposed and the soil appears sandy. The specimens are:

738.—May be a chloritized gneiss. Mica, quartz, and a green mineral which looks like serpentine.

739.—Crinkled schist or chlorite schist.

740.—Gabbro?

741.—Ripidolite.

742.—Chloritized mica schist.

743.—Thin, laminated, pale-green schist.

744.—Pearly soapstone with rusty cavities.

745.—Compact serpentine containing pyrite (?). Dark-green with bands of lighter green. A typical serpentine.

Areas 19 to 28.—All of these areas occur in the gabbro and should be treated as part of that area. The areas are as follows:

19.—Carsins area.

20.—Hickory area.

21.—Area south of Hickory.

22.—Area south of Area 21.

23, 24.—Two areas north of Gibson.

25.—Belair area.

26.—Wimbledon area.

27.—Fallston area.

28.—Small area between 26 and 27.

Map showing Serpentine areas in Harford County, and rock specimen numbers.

Scale, one inch equals one mile

Briefly the localities are these: At Carsins an area about a mile long and 400 to 500 feet wide.

South of Hickory there are three areas, the boundaries of the two to the south being impossible to determine since the area is a serpentinized phase of the gabbro and the rock grades into the gabbro. The area just at Hickory is about a mile in length and 400 or 500 feet wide.

The two areas north of Gibson appear like two small and narrow dikes which have been altered to serpentine.

East of Belair and to the south of the road to Churchville there is a peculiar fibrous hornblende rock. It shows crystals of hornblende as black spots in a lighter green groundmass.

Between Wimbledon and Fallston are three areas as mapped. The direction of these is nearly north and south following the direction of the gabbro boundary at that place.

A catalogue of specimens collected from these different areas is as follows:

Hickory area: 877, 878, 880, 881, 882, 883, 884, 885, 886, 887, 888, 952, 953, 970, 971, 972, 973, 1185, 1186, 1187, 1188.

Gibson area: 941, 942, 943, 944, 945, 946, 947, 948, 949, 950.

Belair area: 867, 868, 869, 966, 1119, 1120, 1221, 1222, 1223.

Wimbledon-Fallston areas: 850, 864, 865, 1017, 1018, 1019, 1020, 1021, 1022, 1023, 1024, 1025, 1026, 1027, 1028, 1057, 1058, 1059, 1060, 1061.

LIST OF MINERALS OCCURRING WITH THE SERPENTINE OF HARFORD COUNTY

Actinolite (Amphibole). (344), (380), 69B.[95]

Asbestos. (Area 16.)

Bronzite. (263A) (46B), (47B).

Calcite. (Area 2.)

Chlorite. (333c). Very common.

Chromite. (288). Common in Area 14.

Copper carbonate. (Area 14.)

[95] The numbers refer to the specimens described in the preceding pages. Only a few examples are given although most of these minerals occur many times.

Corundum. (A single loose crystal found in Area 12.)
Diallage. (Pyroxene.) (319), (263A).
Dolomite. (45B).
Epidote. (43B), (55B).
Feldspar. (263A). (Also occurs in large masses with quartz.)
Farnet? (52B).
Hornblende, green compact. (61B), (62B). Quite common.
Iron pyrites.
Limonite. (522).
Magnesite. (287).
Muscovite? (53B).
Olivine. (46B).
Opal. (524), (443).
Quartz. (69B). (Also occurs in large pure veins.)
Ripidolite. (286).
Serpentine.
Talc or steatite. (445). Very common.
Zoisite. (287).

GEOLOGICAL OCCURRENCE AND AGE OF THE HARFORD COUNTY SERPENTINES

As has been mentioned above, the serpentines of Harford County occur in the gneiss and the mica schists and, in general, follow the strike of these rocks very closely. They are clearly younger than the sedimentary gneisses and mica schists which are regarded by Bascom as of the Hudson River series in Cecil County and with which they occur for they cut through them.

With relation to the igneous rocks their age is not so clearly defined, at least in Harford County. Contacts with the gabbro were not found and where the serpentine touched the granite the latter rock was so much disintegrated by weathering that nothing could be seen. The most reasonable hypothesis is that the serpentine and the gabbro were practically contemporaneous in intrusion. This would seem to be indicated by the close relationship of several of the areas to the gabbro

and the undoubted gabbroic origin of several of the masses. The more basic areas may have simply been differentiation facies of the gabbro magma.

SUMMARY AND CONCLUSIONS

The foregoing detailed descriptions bring out the following facts in regard to the areal distribution and mode of occurrence of the serpentine; the original rocks from which they were derived; and the processes or metamorphism through which the original rocks have passed to their present state of serpentization. These briefly stated are as follows:

In that part of the Piedmont Plateau which occurs in Hartford County there are, in the gneisses and mica schists, two series of long and narrow lenses of serpentine and other basic magnesian rocks. Considered as a unit the main body consists of one broad band of serpentine following the general strike of the gneiss, accompanied by a number of smaller, elongated masses which are more abundant on the north of the main area. The second and less prominent series is farther to the north and runs parallel to the first. Besides these there are several serpentinized areas in the gabbro which are probably entirely distinct from the others, being simply less feldspathic parts of the gabbro which have become serpentinized. There are in all 28 areas as indicated on the map and enumerated in the text.

Geologically the serpentines are intruded masses within the sedimentary series or are local facies of the gabbro. They trend approximately parallel to the strike of the older rocks and possibly follow the direction of minor folds of the sedimentary series. That the rocks were originally eruptives is shown by the study of the thin sections under the microscope. Contacts with the older rocks are rare and the whole region is so much weathered and covered with soil that the field phenomena of intrusion can seldom be observed.

The rocks from which the serpentines were originally derived apparently fall into three main divisions which, in turn, may themselves be simply modifications of a single original gabbroic magma.

The types recognized are:

I. Serpentines derived from feldspar-poor gabbros or from pyroxenites

IIa. Serpentines derived from pyroxene-amphibole-olivine rocks.

b. Serpentines derived from amphibole-olivine rocks.

III. Serpentines derived from pure olivine rocks.

The serpentines from the second class apparently represent two processes of serpentinization of the same original rock. In the first (a) the original pyroxene was changed to serpentine before it was entirely uralitized; in the second (b) and most general class, all the pyroxene was first changed to fibrous or compact amphibole and this, in turn, has been wholly, or in part, altered to serpentine. In several instances the rocks have been uralitized without serpentinization having taken place at all.

A final change is sometimes observed by which the serpentine is altered into a mass of talc and a carbonate from which much of the carbonate has apparently been removed.

Serpentine derived from feldspar-poor gabbros or pyroxenites are represented in the Glades (Area 2), Bald Hill-Scarboro-Deer Creek Area (Area 4), Macton Area (Area 7), Ady Area (Area 11), and Federal Hill Area (Area 17). In the majority of the thin sections examined from these areas there is little indication of feldspar, the slides showing an alteration to serpentine from hornblende which itself may have been, and probably was, derived from an original pyroxene. In other slides the profusion of epidote indicates an alteration from a rock containing feldspar. Besides the slides, many of the hand specimens, especially from the Bald Hill-Scarboro-Deer Creek area, show the gabbro-like character of the rock when it is but partially altered. The Little Deer Creek Area (Area 18) includes fragments of what look like gabbro or pyroxenite, and should probably be included here. All of the areas in the main gabbro mass to the south (Areas 19 to 28) show the characteristics of pyroxenites or feldspar-poor gabbros, and these areas should be included here. Area 5 and the Castleman Area are among those in the gabbro.

Serpentine derived from pyroxene-amphibole-olivine or amphibole-

olivine rocks are represented by the areas at Cherry Hill (Area 12), Chrome Hill (Area 13), and Coopstown-Jarrettsville (Area 14). The thin sections of rocks from these areas indicate olivine-bronzite or olivine hornblende rocks. A single specimen from the Coopstown-Jarrettsville Area seems to have been a pure fibrous hornblende rock with no olivine but the other specimens from the same area show the presence of olivine.

Serpentines derived from original olivine rocks are shown by the specimens from the Cardiff Area (Area 15). In the thin sections from this area none of the original mineral remains, but the arrangement of the ore particles indicates an original olivine rock. It is quite probable that the serpentine of the Broad Creek Area (Area 2) is of the same origin for in a number of slides the ore dust is scattered through the rock in a way which suggests its derivation from an olivine rock.

Serpentines derived from rocks which are indeterminate, usually owing to the decomposed state of the rocks, are represented by Areal, the two small dikes north of Macton (Area 8), the soapstone knoll southwest of Macton (Area 9), that at Mill Green, and that between Pylesville and Clermont Mills (Area 16).

As far as determinable in Harford County, there is no evidence that any of the serpentines have been derived from limestones or dolomites, as held by Rand for the Fritz Island, Pennsylvania, serpentines; and by Britton for part of the serpentines of Staten Island.

Compared with the other serpentines of Maryland those of Harford County seem to have originated chiefly from pyroxenites, rather than from olivine rocks, to which they are usually ascribed in Cecil and Baltimore counties.

The changes through which the rocks have passed in the process of metamorphism to the present condition have already been indicated by the foregoing division of the serpentine into three classes.

Serpentines of the first class—that is, those which were derived from Feldspar-poor gabbro or pyroxenite—show an alteration of the pyroxene to hornblende. Williams speaks of the alteration of the pyroxene of the olivine-bearing rocks in the neighborhood of Baltimore as being first always to hornblende. In Harford County this alteration seems

to have taken place as well in rocks which had no olivine as an original constituent. Subsequent to or contemporaneous with this uralitization, the hornblende was altered to serpentine but still resisting the form of the amphibole cleavage. The feldspar of the gabbro, when it occurs, is in every case entirely altered to epidote. Of this section 71B is a good example.

In the formation of serpentine from pyrozene-olivine rocks the change of the pyroxene also seem to have been first to hornblende. This is exactly the case described by Williams and is given by him as the origin of the Bare Hills serpentine. In Harford County the olivine is almost entirely altered to serpentine and the pyroxene to hornblende which in turn is, in some cases, nearly or entirely altered to serpentine. It retains in most instances the form of the amphibole cleavage as is shown by the arrangement of the ore particles. Slide 1285 is an interesting example for in this the "ore" is arranged in very minute particles along the rhomboidal cleavage of the amphibole. In serpentines derived from amphibole it is usually the case that the ore is massed in large grains or crystals.

The olivine rocks are only represented by the serpentines of Cardiff and possibly Broad Creek. Both of these are compact serpentines and are the areas in which the only workable deposits of serpentine occur. This would seem to indicate that all the massive serpentines are derived from an olivine rock.

In conclusion, all of the serpentines of Harford County whose origin could be traced—constituting the greater part of the areas described—have been derived from intrusive rocks; and that there is no indication of any of them being from sedimentary rocks. The original sources were, for the most part, pyroxenites or feldspar-poor gabbros, and were probably simply a phase of the main gabbroic invasion to the south, and were probably contemporaneous or nearly so. There are a few areas in which the serpentines were derived from peridotites; some of them from olivine-pyroxene rocks and other from what were probably pure dunites. Of the areas which were indeterminate none are of importance; all being of small size, or when long, very narrow.

It is a notable fact that the areas which are of olivine or of olivine-pyroxene origin, lie in two lines. The more important of the two is the one consisting of the Broad Creek, Cherry Hill, Chrome Hill, and Coopstown-Jarrettsville areas. Upon either side of this line are areas which were derived from pyroxene rocks. The other line includes the area at Cambria and may possibly also include the one on Little Deer Creek. Another point to be noted may be the fact that the Bald Hill-Scarboro-Deer Creek Area which seems most clearly to have had a gabbroic origin, and the Glades Area just to the north of it which may possibly be connected with it at a short distance beneath the surface, lies to the north of what appears to be a syncline pitching to the southeast, while to the south lies the great gabbro flow. If this narrow northward member is a contemporaneous part of the gabbro flow it may possibly indicate the other limb of the sheet with its inferred deep-seated connection.

VITA

Albert Johannsen was born at Belle Plains, Iowa, December 3, 1874. He obtained his elementary education at the graded schools of State Center, Iowa, and was there graduated from the High School. He entered the University of Illinois in the fall of 1890 and was graduated with the degree of Bachelor of Science, from the College of Engineering in June, 1894. After practicing engineering for three years, he entered the University of Utah and was there graduated with the degree of Bachelor of Science in General Science, in June, 1898. The following two years he again followed his engineering profession and in the fall of 1900 entered the Johns Hopkins University at which he has studied until the present time.

His field experience was gained as topographical assistant on the United States Geological Survey during the field season of 1897, and as geological assistant with the Maryland Geological Survey during the field seasons of 1901 and 1902.

During the year 1901–02 he held the University Scholarship and was appointed Fellow in Geology for the year 1902–03.